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Aggregate Resources Inventory of Galway and Cavendish Township Peterborough County

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Abstract

This report includes an inventory and evaluation of sand and gravel resources as well as a discussion of bedrock aggregate potential for Galway and Cavendish Township in Peterborough County. This report is based on a detailed field assessment undertaken in the summer of 1990 and on previous studies in the area. The investigation was conducted to delineate and determine the quality and quantity of aggregate within the area to help ensure sufficient aggregate resources are available for future use.

In general, the township contains only limited resources of sand and almost no resources of gravel suitable for crushing. Several deposits, however, have been selected for possible resource protection at the primary and secondary levels of significance. These deposits are capable of meeting some of the local demand for predominantly low-specification aggregate products. The township presently relies on aggregate imported from surrounding areas to meet much of its aggregate needs. The township's aggregate supply is also supplemented through the extraction of extremely weathered Precambrian bedrock from numerous pits. This weathered bedrock is similar in texture to coarse sand.

Potential resources of high quality aggregate do exist in the township within two Selected Bedrock Resource Areas. These areas are underlain by Paleozoic bedrock of the Gull River and Bobcaygeon formations which are suitable for a wide variety of crushed stone products. An estimated 1520 ha are currently available for extraction in these selected deposits, containing possible resources of 720 million tonnes. In addition, hard and durable Precambrian bedrock is an alternate potential source of crushed stone in the area.

Selected Resource Areas are not meant to be permanent, single land use units. They represent areas in which a major resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection.

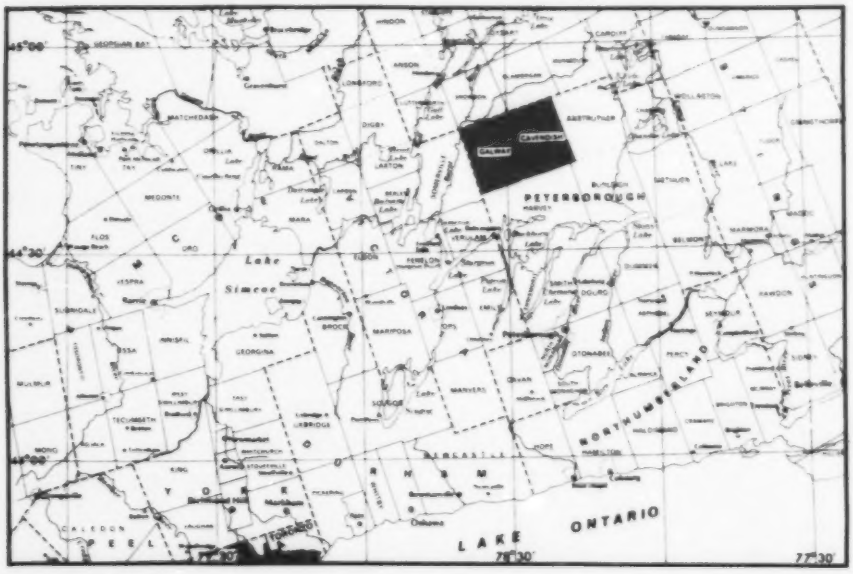

Figure 1. Key map showing location of Galway and Cavendish Township, Peterborough County, scale 1:1 800 000.

Résumé

Ce rapport comprend un inventaire et une évaluation des ressources en sable et gravier, ainsi qu'un exposé sur le potential en agrégat du substratum du canton de Galway et Cavendish dans le comté de Peterborough. Il est basé sur des études préalables du secteur ainsi qu'une évaluation détaillée faite sur le terrain au cours de l'été 1990. Ces études ont été entreprises dans l'intention de délimiter la présence d'agrégats dans le secteur et d'en déterminer la qualité et la quantité afin de s'assurer que la région possède des ressources en agrégats suffisantes pour des utilisations futures.

En général, le canton possède des quantités limitées de sable et très peu de ressources en gravier se prêtant au concassage. Plusieurs dépôts, cependant, ont été sélectionnés comme réserves de ressources d'importance première et secondaire. Ils pourraient subvenir à la demande locale de produits d'agrégats de qualité inférieure. On transporte présentement dans le canton des agrégats des régions avoisinantes. En plus, on entrait des nombreuses carrières le socle précambrien très désagrégé dont la texture ressemble à celle du gros sable.

Des ressources potentielles d'agrégats de haute qualité existent dans deux zones rocheuses sélectionnées. Celles-ci reposent sur le socle paléozoïque incliné des formations Gull River et Bobcaygeon qui les deux pourraient rendre une grande variété de produits de pierre concassée. On pourrait extraire actuellement environ 1520 ha de produits de ces dépôts qui renferment des ressources éventuelles s'élevant à 720 millions de tonnes. D'ailleurs, le socle précambrien dur et solide est une autre source possible de pierre concassée dans cette région.

Les zones sélectionnées pour leurs ressources ne sont pas destinées à un usage unique et permanent. Elles représentent des zones dans lesquelles une ressource importante a été reconnue et peuvent être réservées entièrement ou partiellement pour l'exploitation et/ou comme réserves de ressources.

Cette publication est disponsible en anglais seulement.

Aggregate Resources Inventory of Galway and Cavendish Township

Peterborough County

By Staff[1] of the Sedimentary and Environmental Geoscience Section

1. Project Supervisor: I. Szoke; field work and report by G.R. Jones; compilation and drafting by Staff of the Aggregate Assessment Office. Assistance with review provided by the Regional Geologist, Ministry of Northern Development and Mines, Tweed, Ontario and the Mineral Resources Staff, Minden District Office, Ministry of Natural Resources.

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Introduction

Mineral aggregates, which include bedrock-derived crushed stone as well as naturally formed sand and gravel, constitute the major raw material in Ontario's road-building and construction industries. Very large amounts of these materials are used each year throughout the Province. For example, in 1987, the total tonnage of mineral aggregates extracted was 142 million tonnes, greater than that of any other metallic or non-metallic commodity mined in the Province (Ontario Ministry of Northern Development and Mines 1989).

Although mineral aggregate deposits are plentiful in Ontario, they are fixed-location, nonrenewable resources which can be exploited only in those areas where they occur. Mineral aggregates are characterized by their high bulk and low unit value so that the economic value of a deposit is a function of its proximity to a market area as well as its quality and size. The potential for extractive development is usually greatest in areas where land use competition is extreme. For these reasons the availability of adequate resources for future development is now being threatened in some areas.

Comprehensive planning and resource management strategies are required to make the best use of available resources, especially in those areas experiencing rapid development. Such strategies must be based on a sound knowledge of the total mineral aggregate resource base at both local and regional levels. The purpose of the Aggregate Resources Inventory is to provide the basic geological information required to include potential mineral aggregate resource areas in planning strategies. The reports should form the basis for discussion on those areas best suited for possible extraction. The aim is to assist decision-makers in protecting the public well-being by ensuring that adequate resources of mineral aggregate remain available for future use.

This report is a technical background document, based for the most part on geological information and interpretation. It has been designed as a component of the total planning process and should be used in conjunction with other planning considerations, to ensure the best use of the resources.

The report includes an assessment of sand and gravel resources as well as a discussion on the potential for bedrock-derived aggregate. The most recent information available has been used to prepare the report. As new information becomes available, revisions may be necessary.

Part I — Inventory Methods

FIELD AND OFFICE METHODS

The methods used to prepare the report primarily involve the interpretation of published geological data such as bedrock and surficial geology maps and reports (*see References*) as well as field examination of potential resource areas. Field methods include the examination of natural and man-made exposures of granular material. Most observations are made at quarries and sand and gravel pits located from records held by the Ontario Ministry of Transportation, the Ontario Geological Survey, and Regional and District offices of the Ontario Ministry of Natural Resources. Observations made at pit sites include estimates of the total face height and the proportion of gravel- and sand-sized fragments in the deposit. Observations are also made of the shape and lithology of the particles. These characteristics are important in estimating the quality and quantity of the aggregate. In areas of limited exposure, subsurface materials may be assessed by hand augering and test pitting.

Deposits with potential for further extractive development or those where existing data are scarce, are studied in greater detail. Representative sections in these deposits are sampled in 11 to 45 kg units from existing pit faces or from test pits. The samples are analyzed for grain size distribution, and in some cases the Los Angeles abrasion and impact test, absorption, and Magnesium Sulphate soundness tests and petrographic analyses are carried out. Analyses are performed either in the laboratories of the Ontario Ministry of Transportation, or in the Geoscience Laboratory, Ontario Geological Survey.

The field data are supplemented by pit information on file with the Soils and Aggregates Section of the Ontario Ministry of Transportation. Data contained in these files include field estimates of the depth, composition and "workability" of deposits as well as laboratory analyses of the physical properties and chemical suitability of the aggregate. Information concerning the development history of the pits and acceptable uses of the aggregate is also recorded. The locations of additional sources were obtained from records held by Regional and District offices of the Ontario Ministry of Natural Resources. The co-operation of the above-named groups in the compilation of inventory data is gratefully acknowledged.

Aerial photographs at various scales are used to determine the continuity of deposits, especially in areas where information is limited. Water well records, held by the Ontario Ministry of the Environment, are used in some areas to corroborate deposit thickness estimates or to indicate the presence of buried granular material. These records are used in conjunction with other evidence.

Topographic maps of the National Topographic System, at a scale of 1:50000, are used as a compilation base for the field and office data. The information is then transferred to a base map, also at a scale of 1:50000. These base maps are prepared by the Land and Resource Information Branch, Ontario Ministry of Natural Resources with information taken from maps of the National Topographic System by permission of Energy, Mines and Resources Canada, for presentation in the report.

RESOURCE TONNAGE CALCULATION TECHNIQUES

SAND AND GRAVEL RESOURCES

Once the interpretative boundaries of the aggregate units have been established, quantitative estimates of the possible resources available can be made. Generally, the volume of a deposit can be calculated if its areal extent and average thickness are known or can be estimated. The computation methods used are as follows. First, the area of the deposit, as outlined on the final base map, is calculated in hectares. The thickness values used are an approximation of the deposit thickness, based on the face heights of pits developed in the deposit or on subsurface data such as test holes and water well logs. Tonnage values can then be calculated by multiplying the volume of the deposit by 17 700 (the density factor). This factor is approximately the number of tonnes in a 1 m thick layer of sand and gravel, 1 ha in extent, assuming an average density of 1770 kg/m^3.

Tonnage = Area x Thickness x Density Factor

Tonnage calculated in this manner must be considered only as an estimate. Furthermore, such tonnages represent amounts that existed prior to any extraction of material (i.e., original tonnage) (Table 1, Column 4).

The Selected Sand and Gravel Resource Areas in Table 3 are calculated in the following way. Two successive subtractions are made from the total area. Column 3 accounts for the number of hectares unavailable because of the presence of permanent cultural features and their associated setback requirements. Column 4 accounts for those areas that have previously been extracted (e.g., wayside and abandoned pits are included in this category). The remaining figure is the area of the deposit currently available for extraction (Column 5). The available area is then multiplied by the estimated deposit thickness and the density factor (Column 5 x Column 6 x 17 700) to give an estimate of the sand and gravel tonnage (Column 7) presently available for extractive development and/or resource protection.

Resource estimates are calculated for deposits of primary significance. Resource estimates for deposits of

secondary and tertiary significance are not calculated in Table 3, however, the aggregate potential of these deposits is discussed in the report.

BEDROCK RESOURCES

The method used to calculate resources of bedrock-derived aggregate is much the same as that described above. The areal extent of bedrock formations overlain by less than 8 m of unconsolidated overburden is determined from bedrock geology maps, drift thickness and bedrock topography maps, and from the interpretation of water well records. The measured extent of such areas is then multiplied by the estimated quarriable thickness of the formation, based on stratigraphic analyses and on estimates of existing quarry faces in the unit. In some cases a standardized estimate of 18 m is used for thickness. Volume estimates are then multiplied by the density factor [the estimated weight in tonnes of a 1 m thick section of rock, 1 ha in extent].

Resources of dolostone are calculated using a density factor of 2649 kg/m^3, sandstone resources are calculated using a density estimate of 2344 kg/m^3 and shale resources are calculated with a factor of 2408 kg/m^3.

UNITS AND DEFINITIONS

The measurements and other primary data available for resource tonnage calculations are given in Metric units in the text and on the tables which accompany the report. Data are generally rounded off in accordance with the Ontario Metric Practice Guide (Metric Committee 1975).

The tonnage estimates made for sand and gravel deposits are termed possible resources (*see* Glossary, Appendix B) in accordance with terminology of the Ontario Resource Classification Scheme (Robertson 1975, p.7) and with the Association of Professional Engineers of Ontario (1976).

Part II — Data Presentation and Interpretation

Two maps, each portraying a different aspect of the aggregate resources in the area, accompany the report. Map 1, "Sand and Gravel Resources", gives a comprehensive inventory and evaluation of the sand and gravel resources in the report area. Map 2 "Bedrock Resources", shows the distribution of Paleozoic bedrock formations, the areas of undifferentiated Precambrian bedrock, the thickness of overlying unconsolidated sediments and identifies the Selected Bedrock Resource Areas.

MAP 1: SAND AND GRAVEL RESOURCES

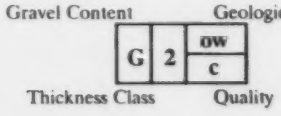
Map 1 shows the extent and quality of sand and gravel deposits within the study area and an evaluation of the aggregate resources. The map is derived from existing surficial geology maps of the area or from aerial photograph interpretation in areas where surficial mapping is incomplete.

The present level of extractive activity is also indicated on Map 1. Sand and gravel pits are identified by a numbered dot on the map and described in Table 2. Each description notes the estimated face height of the pit and the estimated percentage of gravel it contains.

Map 1 also presents a summary of available information related to the quality of aggregate contained in all the known aggregate deposits in the study area. Much of this information is contained in the symbols which are found on the maps. The Deposit Symbol appears for each mapped deposit and summarizes important genetic and textural data. The Texture Symbol is a circular proportional diagram which displays the grain size distribution of the aggregate in areas where bulk samples were taken.

DEPOSIT SYMBOL

The Deposit Symbol is similar to those used in soil mapping and land classification systems commonly in use in North America. The components of the symbol indicate the gravel content, thickness of material, origin (type) and quality limitations for every deposit shown on Map 1. These components are illustrated by the following example:



This symbol identifies an outwash deposit 3 to 6 m thick containing more than 35% gravel. Excess silt and clay may limit uses of the aggregate in the deposit.

The "gravel content" and "thickness class" are basic criteria for distinguishing different deposits. The "gravel content" symbol is an upper case "S" or "G". The "S" indicates that the deposit is generally "sandy" and that gravel-sized aggregate (greater than 4.75 mm) makes up less than 35% of the whole deposit. "G" indicates that the deposit contains more than 35% gravel.

The "thickness class" indicates a depth range which is related to the potential resource tonnage for each deposit. Four thickness class divisions have been established as shown in the legend for Map 1.

Two smaller sets of letters, divided from each other by a horizontal line, follow the thickness class number. The upper series of letters identifies the geologic deposit type (the types are summarized with respect to their main geologic and extractive characteristics in Appendix C) and the lower series of letters identifies the main quality limitations that may be present in the deposit as discussed in the next section.

TEXTURE SYMBOL

The Texture Symbol provides a more detailed assessment of the grain size distribution of material sampled during field study. These symbols are derived from the information plotted on the aggregate grading curves found in the report. The relative amounts of gravel, sand, and silt and clay in the sampled material are shown graphically in the Texture Symbol by the subdivision of a circle into proportional segments. The following example shows a hypothetical sample consisting of 30% gravel, 60% sand, and 10% silt and clay:

Selected Sand and Gravel Resource Areas

All the Selected Sand and Gravel Resource Areas are first delineated by geological boundaries and then classified into three levels of significance: primary, secondary and tertiary. Each area of primary significance is given a deposit number and all such deposits are shown by dark red shading on Map 1.

Selected Sand and Gravel Resource Areas of primary significance are not permanent, single land use units. They represent areas in which a major resource is known to exist, and may be reserved wholly or partially for extractive development and/or resource protection.

Deposits of secondary significance are indicated by medium red shading on Map 1. Such deposits are believed to contain significant amounts of sand and gravel. Although deposits of secondary significance are

not considered to be the "best" resources in the report area, they may contain large quantities of sand and gravel and should be considered part of the aggregate supply of the area.

Areas of tertiary significance are indicated by light red shading. They are not considered to be important resource areas because of their low available resources, or because of possible difficulties in extraction. Such areas may be useful for local needs but are unlikely to support large-scale development.

The process by which deposits are evaluated and selected involves the consideration of two sets of criteria. The main selection criteria are site specific, related to the characteristics of individual deposits. Factors such as deposit size, aggregate quality, and deposit location and setting are considered in the selection of those deposits best suited for extractive development. A second set of criteria involves the assessment of local aggregate resources in relation to the quality, quantity and distribution of resources in the region in which the report area is located. The intent of such a process of evaluation is to ensure the continuing availability of sufficient resources to meet possible future demands.

SITE SPECIFIC CRITERIA

Deposit Size

Ideally, selected deposits should contain available sand and gravel resources large enough to support a commercial pit operation using a stationary or portable processing plant. In practice, much smaller deposits may be of significant value depending on the overall reserves in the rest of the project area. Generally, deposits in Class 1 (greater than 6 m thick), and containing more than 35% gravel are considered to be most favourable for commercial development. Thinner deposits may be valuable in areas with low total resources.

Aggregate Quality

The limitations of natural aggregates for various uses result from variations in the lithology of the particles composing the deposit, and from variations in the size distribution of these particles.

Four indicators of the quality of aggregate may be included in the deposit symbols. They are: gravel content (G or S), fines (C), oversize (O), and lithology (L).

Three of the quality indicators deal with grain size distribution. The gravel content (G or S) indicates the suitability of aggregate for various uses. Deposits containing at least 35% gravel in addition to a minimum of 20% material greater than the 26.5 mm sieve are considered to be the most favourable extractive sites, since this content is the minimum from which crushed products can be economically produced.

Excess fines (high silt and clay content) may severely limit the potential use of a deposit. Fines content in excess of 10% may impede drainage in road subbase aggregate and render it more susceptible to the effects of frost action. In asphalt aggregate, excess fines hinder the bonding of particles. Deposits known to have a high fines content are indicated by a "C" in the quality portion of the Deposit Symbol.

Deposits containing more than 20% oversize material (greater than 10 cm in diameter) may also have use limitations. The oversize component is unacceptable for all concrete aggregate and for road-building aggregate, so it must be either crushed or removed during processing. Deposits known to have an appreciable oversize component are indicated by an "O" in the quality portion of the Deposit Symbol.

Another indicator of the quality of an aggregate is lithology. Just as the unique physical and chemical properties of bedrock types determine their value for use as crushed rock, so do various lithologies of particles in a sand and gravel deposit determine its suitability for various uses. The presence of objectionable lithologies such as chert, siltstone and shale, even in relatively small amounts, can result in a reduction in the quality of an aggregate, especially for high quality uses such as concrete and asphalt. Similarly, highly weathered, very porous and friable rock can restrict the quality of an aggregate. Deposits known to contain objectionable lithologies are indicated by an "L" in the quality component of the Deposit Symbol.

If the Deposit Symbol shows either "C", "O", or "L" or any combination of these indicators, the quality of the deposit is considered to be reduced for some uses of the aggregate. No attempt is made to quantify the degree of limitation imposed. Assessment of the four indicators is made from published data, from data contained in files of both the Ontario Ministry of Transportation (MTO) and the Sedimentary and Environmental Geoscience Section of the Ontario Geological Survey, and from field observations.

Quality data may also appear in Table 9, where the results of MTO quality tests are listed by test type and sample location. The types of tests conducted and the test specifications are explained in Appendixes B and E, respectively.

Analyses of unprocessed samples obtained from test holes, pits or sample sites are plotted on grain size distribution graphs. On the graphs are the Ontario Ministry of Transportation's gradation specification envelopes for aggregate products: Granular A and Granular B Type I; Hot-Laid Asphaltic Sand nos. 1,2,3,4, and 8; and concrete sand. By plotting the gradation curves with respect to the specification envelopes, it can be determined how well the unprocessed sampled material meets the criteria for each product. These graphs, called Aggregate Grading Curves, follow the tables in the report.

Location and Setting

The location and setting of a resource area has a direct influence on its value for possible extraction. The evaluation of a deposit's setting is made on the basis of natural

and man-made features which may limit or prohibit extractive development.

First, the physical context of the deposit is considered. Deposits with some physical constraint on extractive development, such as thick overburden or high water table, are less valuable resource areas because of the difficulties involved in resource recovery. Second, permanent man-made features, such as roads, railways, powerlines and housing developments, which are built on a deposit, may prohibit its extraction. The constraining effect of legally required setbacks surrounding such features is included in the evaluation. A quantitative assessment of these constraints can be made by measurement of their areal extent directly from the topographic maps. The area rendered unavailable by these features is shown for each resource area in Table 3 (Column 3).

The assessment of sand and gravel deposits with respect to local land use and to private land ownership is an important component of the general evaluation process. These aspects of the evaluation process are not considered further in this report, but readers are encouraged to discuss them with personnel of the pertinent District Office of the Ontario Ministry of Natural Resources.

REGIONAL CONSIDERATIONS

In selecting sufficient areas for resource development, it is important to assess both the local and the regional resource base, and to forecast future production and demand patterns.

Some appreciation of future aggregate requirements in an area may be gained by assessing its present production levels and by forecasting future production trends. Such an approach is based on the assumptions that production levels in an area closely reflect the demand and that the present production "market share" of an area will remain roughly at the same level.

The aggregate resources in the region surrounding a project area should be assessed in order to properly evaluate specific resource areas and to adopt optimum resource management plans. For example, an area that has large resources in comparison to its surrounding region constitutes a regionally significant resource area. Areas with high resources in proximity to large demand centres, such as metropolitan areas, are special cases.

Although an appreciation of the regional context is required to develop comprehensive resource management techniques, such detailed evaluation is beyond the scope of this report. The selection of resource areas made in this study is based primarily on geological data or on considerations outlined in preceding sections.

MAP 2: BEDROCK RESOURCES

Map 2 is an interpretative map derived from bedrock geology, drift thickness and bedrock topography maps, water well data from the Ontario Ministry of the Environment, oil and gas well data from the Aggregate and Petroleum Resources Section (Ontario Ministry of Natural Resources) and from geotechnical test hole data from various sources. Map 2 is based on concepts similar to those outlined for Map 1.

The geological boundaries of the Paleozoic bedrock units are shown by a dashed line. The areas of undifferentiated Precambrian bedrock are labelled as such on Map 2. Isolated Paleozoic outcrops are indicated by an "X". Two sets of contour lines delineate areas of less than 1 m of drift, areas of 1 to 8 m of drift and areas of greater than 8 m of drift. The extent of these areas of drift are shown by three shades of blue. The darkest shade indicates where bedrock outcrops or is within 1 m of the ground surface. These areas constitute potential resource areas because of their easy access. The medium shade indicates areas where drift cover is up to 8 m thick. Quarrying is possible in this depth of overburden and these zones also represent potential resource areas. The light shade indicates bedrock areas overlain by greater than 8 m of drift, a depth generally considered to be too great to allow economic extraction (unless part of the overburden is composed of economically attractive deposits). Outside of these delineated areas are areas of undifferentiated Precambrian bedrock, with varying thicknesses of drift cover.

Other inventory information presented on Map 2 is designed to give an indication of the present level of extractive activity in the report area. Quarries are identified by a number which refers to the descriptions in Table 5. Each description notes an estimate of face height. Two additional symbols may appear on the map. An open dot indicates the location of a selected water well which penetrates bedrock. The overburden thickness is shown in metres beside the open dot. Similarly, test hole locations appear as a point symbol with the depth to bedrock shown in metres beside it. The test holes may be further described in Table 7.

Selection Criteria

Criteria equivalent to those used for sand and gravel deposits are used to select Paleozoic bedrock areas most favourable for extractive development. The areas of Precambrian bedrock are not evaluated in this report.

The evaluation of Paleozoic bedrock resources is made primarily on the basis of performance and suitability data established by laboratory testing at the Ontario Ministry of Transportation. The main characteristics and uses of the bedrock units found in southern Ontario are summarized in Appendix D.

Deposit "size" is related directly to the areal extent of thin drift cover overlying favourable bedrock formations. Since vertical and lateral variations in Paleozoic bedrock units are much more gradual than in sand and gravel deposits, the quality and quantity of the resource are usually consistent over large areas.

Quality of the aggregate derived from specific bedrock units is established by the performance standards previously mentioned. Location and setting criteria and

regional considerations are identical to those for sand and gravel deposits.

The Precambrian Shield rocks are generally more complex and variable than the Paleozoic rocks of Ontario. They often show wide variations in mineralogy, texture (grain size), joint patterns and degree of weathering, even within specific rock types and over relatively short distances. As these factors are considered important in determining the suitablity of the bedrock for use as aggregate, the aggregate potential may also vary considerably from location to location.

Careful selection is especially important if the bedrock is to be used as concrete aggregate. Deleterious chemical reactions may develop in the concrete which can lead to its eventual deterioration. Fortunately, these chemical reactions should not influence the use of bedrock-derived aggregate for such uses as roadbase material. However, highly weathered, very porous and friable rock should be avoided for all uses.

For these reasons, no specific Precambrian bedrock resources have been selected for resource protection. A summary of the bedrock resources on a regional level is included in the Bedrock Geology and Resource Potential section.

Selected Resource Areas

Selection of Bedrock Resource Areas has been restricted to a single level of significance. Three factors support this approach. First, quality and quantity variations are gradual. Second, the areal extent of a given quarry operation is much smaller than that of a sand and gravel pit producing an equivalent tonnage of material, and third, since crushed bedrock has a higher unit value than sand and gravel, longer haul distances can be considered. These factors allow the identification of alternative sites having similar development potential. The Selected Areas, if present, are shown on Map 2 by a line pattern and the calculated available tonnages are given in Table 6.

Selected Bedrock Resource Areas shown on Map 2 are not permanent, single land use units. They represent areas in which a major bedrock resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection.

Part III — Assessment of Aggregate Resources in Galway and Cavendish Township

LOCATION AND POPULATION

Galway and Cavendish Township occupies an area of 47 878 ha in the northwestern part of Peterborough County, southern Ontario. The community of Kinmount, located on the northwestern boundary of the township, is the only major population centre in the report area. The study area is covered by the Burleigh Falls (31 D/9), Fenelon Falls (31 D/10), Minden (31 D/15) and Gooderham (31 D/16) map sheets of the National Topographic System at a scale of 1:50 000.

The population of the township was 493 in 1988, an increase of approximately 44% since 1978 (Ontario Ministry of Intergovernmental Affairs 1979; Ontario Ministry of Municipal Affairs 1991). Most residents live in the community of Kinmount or in rural-residential areas. In addition, there is also a significant seasonal population as the township is a popular tourist area. Cottages line the shores of many lakes in the area, including Crystal, Salmon, Mississagua and Catchacoma lakes. The combination of a steadily growing permanent population and a large seasonal population has resulted in a strong demand for aggregate in the township. Most of this demand is currently met by importing aggregate from outside the township.

Major transportation routes in the western part of the township include King's Highway 121, Secondary Highway 649 and a network of township roads. Secondary Highway 507 provides access in the eastern part of the township. Forest and cottage access roads are also common in the area.

PHYSIOGRAPHY AND SURFICIAL GEOLOGY

The physiography of the township is dominated by the typical "rock knob and ridge" topography of the Canadian Shield (Chapman and Putnam 1984; Mollard 1980). Precambrian bedrock of the shield occurs at or just below the ground surface throughout much of the area; the exception being several areas underlain by Paleozoic bedrock along the southern boundary of the township.

The glacial deposits in the area are a result of the last major advance and melting of a continental ice sheet during the Late Wisconsinan Substage of the Pleistocene Epoch (informally known as the "Great Ice Age"). As the glacial ice advanced over the area in a south to southwesterly direction (Finamore and Bajc 1983; Kaszycki, in prep.), a discontinuous thin cover of stony silty sand to sand till was deposited over the Precambrian bedrock. Thicker deposits of compact, extremely stony, silty sand till overlie the Paleozoic bedrock in the southwestern corner of the report area. These thicker till accumulations are associated with hummocky terrain referred to as the Dummer moraines (Chapman and Putnam 1984). Till is usually not well suited for aggregate use because it contains excess fines and abundant oversize clasts. It may, however, be a potential source of fill in some localities.

As the ice receded northward, a small number of ice-contact deposits were formed close to the ice front. These deposits originated in a variety of depositional environments. A small esker, located south of Union Lake in the northwest part of the township, is one type of ice-contact feature. Eskers are formed by meltwaters flowing and depositing sediments in tunnels under the ice or in reentrants at the ice front. Ice-contact deposits consist of material ranging from sand to coarse gravel and have been important local sources of aggregate in the area.

Outwash features in the report area were deposited by meltwaters flowing in bedrock controlled valleys or basins beyond the ice margin. These flat-lying deposits are located near the community of Kinmount and in and around Kawartha Highlands Provincial Park. They consist predominantly of well-stratified and uniformally bedded sand.

As the ice front receded northward, low-lying areas were inundated by glacial lake waters. Subaqueous fans formed where meltwaters were discharged from the ice directly into a glacial lake (Rust and Romanelli 1975). These fans occur as isolated lobes or fan-shaped bodies and the material tends to become finer towards the surface. Two subaqueous fan deposits, located in the southwestern corner of the report area, consist of fine to medium sand with pockets of fine gravel.

In the shallower parts of the glacial lakes, glaciolacustrine sediments, consisting predominantly of silty fine sand, were laid down. Glaciolacustrine deposits are relatively abundant in the western part of the report area (Finamore and Bajc 1983), however, the sand is too fine for most aggregate uses except fill. Several deposits located in the northwestern corner of the report area have been classified with a dual designation of outwash–glaciolacustrine plain. These deposits contain silty fine sand and silt indicating deposition in a glaciolacustrine environment as well as localized areas of sand and sandy gravel of outwash origin.

Since the disappearance of the ice sheet and lowering of lake waters to present-day levels, organic deposits have been developed in depressions in the land surface and alluvium has been deposited along the courses of creeks and rivers.

EXTRACTIVE ACTIVITY

Numerous sand and gravel pits have been opened in Galway and Cavendish Township. The pits are typically small operations capable of meeting some local

demands for low-specification aggregate. The only sources of high-specification aggregates are two bedrock quarries developed near Highway 507 in the eastern part of the area. A third quarry has been established for the extraction of building stone but is currently inactive. Much of the township's demand for high quality aggregate is being met by importing crushed limestone from outside the area.

SELECTED SAND AND GRAVEL RESOURCE AREAS

Map 1 indicates the deposits containing granular materials in Galway and Cavendish Township. These deposits occupy a total of approximately 1430 ha and contain an original resource tonnage of 47 million tonnes. Many of the deposits have limited potential for extraction because of the restricted quantity of, or poor quality of the available resources they contain, and/or poor resource accessibility. Consequently, only the most significant sources have been suggested for possible resource protection.

Selected Sand and Gravel Resource Area 1 (Map 1), an ice-contact deposit, is considered important as it contains significant quantities of gravelly sand suitable for uses including Granular B Type I in a township where sand and gravel resources are lacking. The Selected Sand and Gravel Resource Area of primary significance occupies a total available area of 15 ha. The area contains possible sand and gravel resources of approximately 1.2 million tonnes.

In addition, a number of deposits have been selected at the secondary level of significance. Although these deposits tend to be more limited with respect to extractive potential than the resources selected at the primary level, they add significantly to the resource base of the report area.

Selected Sand and Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 consists of an ice-contact deposit situated in the western part of the township (Map 1). Pit no. 11 has been opened in the deposit. This pit includes an upper excavation into the crest of the deposit and a lower excavation along the deposit boundary. The upper excavation revealed 2.4 to 3.0 m of gravelly sand with approximately 5 to 25% gravel. Higher concentrations of gravel are concentrated in pockets within the sandy aggregate. This material appears well suited for use as Granular B Type I. The lower excavation exposed 3.0 to 6.1 m of material ranging from silty fine sand to coarse sand with approximately 20% gravel. Selective extraction of the gravelly sand units would be required for the production of Granular B Type I.

Resource Area 1 occupies approximately 16 ha of which 15 ha are currently available for extraction. Assuming an average deposit thickness of 4.6 m, aggregate resources are estimated to be 1.2 million tonnes. The area is readily accessible via the township road network.

Resource Areas of Secondary Significance

In total, 8 resource areas of secondary significance are identified in Galway and Cavendish Township. Included in this total are three outwash–glaciolacustrine plain deposits in the northwestern part of the report area. Pit nos. 2, 3 and 4 have been opened in the easternmost deposit of this grouping. Pit no. 2 exposed 0.9 to 1.5 m of gravelly coarse sand with approximately 10 to 30% gravel. This material appears well suited for the production of Granular B Type I. Similar material is evident in the faces of pit no. 3. Sand is revealed in the 0.9 to 1.2 m faces of pit no. 4. Water was ponded on the floors of pit nos. 2, 3 and 4 and the water table may be encountered within 2 m of the surface in these deposits. Sand, suitable for low-grade aggregate uses, was exposed at the surface of the other two outwash–glaciolacustrine plain deposits.

Another area of secondary significance is an outwash deposit located near Catchacoma Lake in the southeastern part of the township. Pit no. 29 has been developed in this deposit and up to 1.5 m of sand with minor amounts of fine gravel is exposed in the faces. Only limited quantities of aggregate remain in the deposit and the pit is near depletion.

Two ice-contact features, situated near Union Creek, have also been selected at the secondary level. One of these features is a small esker ridge which rises between 2.4 and 6.1 m above the surrounding terrain. Three test pits were excavated to a depth of 1 m in the ridge. The test pits revealed material ranging from sandy gravel suitable for Granular B Type I to coarse crushable gravel with oversize particles. The other feature is an ice-contact deposit located just west of the esker. Sand with minor amounts of fine gravel was the predominant material uncovered in 1 m deep test pits. Bedrock may, however, be encountered close to the surface in parts of this deposit.

The remaining secondary resource areas include two subaqueous fan deposits located in the southwestern corner of the township. Pit no. 15 has been opened in the southernmost feature. Faces in the pit revealed 1.5 to 3.0 m of fine sand with pockets of sandy fine gravel. Similar material may be available elsewhere in these deposits.

Alternate Aggregate Resources

Because of the lack of local sand and gravel resources, weathered gneisses and granites have been extracted as alternate sources of road subbase and fill for the construction of forest and cottage access roads. Typically, the upper 1 to 2 m of weathered bedrock is removed from the underlying, more competent bedrock. The

weathered bedrock has a grain size distribution similar to coarse sand (Figure 3a, Pit 22). Weathered bedrock is not considered to be as durable as glacially derived sands and may not bond well with concrete or asphalt mixes. Magnesium Sulphate Soundness testing of the sample from pit no. 22 yielded a 36% loss, well above specification limits for concrete and asphalt sand products. Consequently, the material appears best suited for low-specification aggregate uses such as Select Subgrade Material.

BEDROCK GEOLOGY AND RESOURCE POTENTIAL

The report area is underlain predominantly by Precambrian bedrock except for four areas along the township's southern boundary which are underlain by younger Paleozoic strata. The bedrock geology of the area is portrayed at a reconnaissance level in Figure 2. Precambrian geological mapping and reports by Satterly (1943), Easton and Bartlett (1984), Easton (1988), Bright (1980, 1981a, 1981b, 1988) and the Ontario Geological Survey (1991) cover portions of the project area.

The Precambrian bedrock in the report area is part of the Central Metasedimentary Belt (Wynne-Edwards 1972) of the Grenville Province of the Canadian Shield. A variety of metasedimentary, metavolcanic and felsic to ultramafic plutonic rock types are included within this belt. Metamorphic and deformational processes are the main causes of an extremely complex bedrock geology (Bright 1988).

A wide variety of Precambrian rocks occur within the township. Carbonate metasedimentary rocks and clastic metasedimentary rocks are common in the area. Large bodies of felsic plutonic rocks also occur. The latter rocks consist predominantly of granitic to granodioritic and tonalitic, massive to gneissic units. Belts of metavolcanic rocks are widespread in the eastern part of the township. Of these rock types, hard and durable gneisses and granites may be the best suited for extractive development.

The Precambrian bedrock within the project area may exhibit wide variations with respect to aggregate quality over relatively short distances. Consequently, any site proposed for quarry development should be tested in detail before extraction occurs. Highly weathered, brittle and friable Precambrian bedrock which appears acceptable for low-specification aggregate uses is common within the report area. There are also many areas that are underlain by more massive, hard and durable rock which appears suitable for a variety of aggregate applications. However, some of the massive coarse-grained felsic plutonic rocks and gneisses with high mica, feldspar and quartz contents may have bonding problems because the smooth cleavage and fracture surfaces of these minerals hinder the adhesion of asphalt and cement mixes. This problem may be circumvented by weathering the rocks for a period of time in stockpiles or by adding chemicals (anti-stripping agents) which erode the smooth surfaces and allow better adhesion. Some granitic rocks can slowly react with the alkalies from Portland cement concrete, resulting in concrete deterioration (Rogers 1985). Although the Precambrian bedrock in the area may meet the Ontario Ministry of Transportation's (MTO) specifications for concrete aggregate, it may not be accepted by MTO for use in Portland cement concrete which will be exposed to de-icing salts. A potential bonding problem between the aggregate and cement could exist. Radioactive mineralization may also occur locally within some rock types in the area and these rocks should be avoided during extraction.

Precambrian bedrock has been quarried in the township for the production of aggregate. Quarry no. 1, located along Highway 507 near Galloway Lake, has 6.1 to 7.6 m high faces of granitic rock. The rock is relatively homogenous and appears to be hard and durable. MTO has tested the aggregate from the quarry and reports that it is suitable for Granular A Type II, Granular B Type I and Granular M. Application of anti-stripping agents would be required for the production of hot-laid asphalt stone.

Sedimentary rocks of Paleozoic age underlie the southwestern corner of the project area and occur as outliers surrounded by Precambrian bedrock elsewhere in the township (Map 2). The outliers are located 2 km northwest of Bass Lake, 3 km northeast of De Gaulle Lake and 1 km west of Mountain Lake. The Paleozoic formations present in the area include the Shadow Lake, Gull River and Bobcaygeon formations (Liberty 1969; Carson 1980).

The Shadow Lake Formation consists primarily of red and green, sandstones and shales which are unsuitable for most aggregate products. These materials were deposited over an uneven Precambrian surface and can vary in thickness from 0 to 12 m. The greatest thicknesses are generally associated with topographic lows in the Precambrian basement. Shadow Lake Formation bedrock usually outcrops in small areas along the base of escarpments formed of Paleozoic strata. These escarpments are the erosional edge of the Paleozoic strata and mark the surface expression of the Paleozoic-Precambrian boundary.

The thin- to thick-bedded, lithographic to fine-grained limestone and dolomitic limestone of the Gull River Formation overlies the Shadow Lake Formation. Beds of shaly and sandy dolostones and limestones also occur within the Gull River Formation strata (Liberty 1969; Carson 1980). The formation forms the cap rock of the escarpments which occur along the Paleozoic-Precambrian boundary and generally increases in thickness away from the boundary. The total thickness of the formation can vary from 21 to 24 m (Liberty 1969), although it may be as thin as 6 m in cliffs along the escarpments.

The Bobcaygeon Formation limestones are typically coarser grained, thicker bedded and more fossiliferous than the underlying Gull River Formation (Armstrong 1990). Black chert nodules and fine-grained

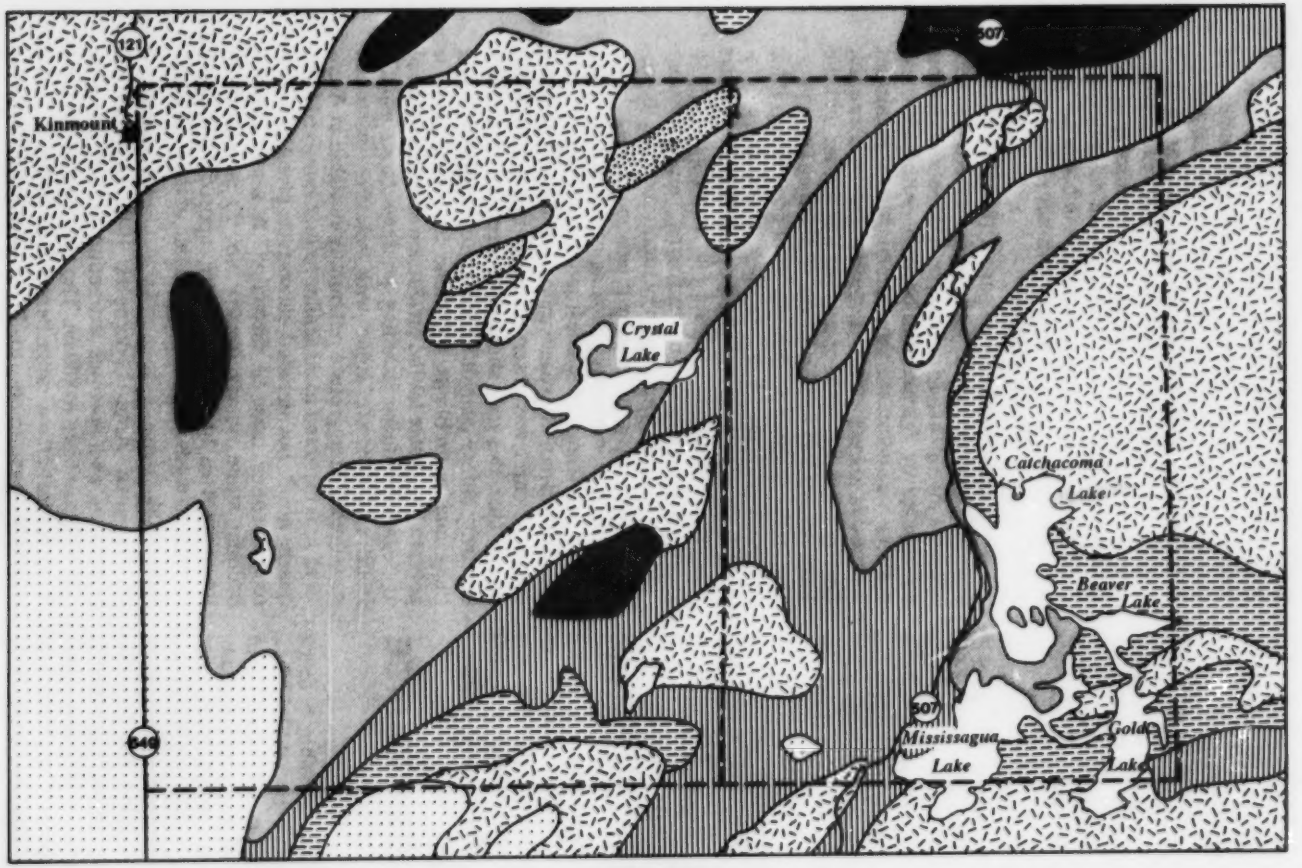


Figure 2. Bedrock geology of Galway and Cavendish Township, scale 1:180 000 (*after* Ontario Geological Survey 1991).

interstitial chert may occur within the Bobcaygeon Formation and the middle part of the formation tends to have a higher shale content (D. Williams, MTO, personal communication, 1991). The Bobcaygeon Formation limestones underlie the southwestern corner of the township. In this area, the Bobcaygeon Formation can reach 20 m in thickness (Derry Michener Booth and Wahl and Ontario Geological Survey 1989).

Bedrock of the Gull River and Bobcaygeon formations are important aggregate sources in southern Ontario. Crushed stone from the Gull River Formation is used in a variety of aggregate applications. Certain beds within the formation, however, are chemically reactive with Portland cement mixes (Rogers 1985). This reaction can result in the deterioration of concrete structures subject to moist environments and/or road salts. Selective extraction of the nonreactive beds may, therefore, be required for the production of some concrete aggregates. The Gull River Formation bedrock is generally well suited for use as hot-laid asphalt, but polishing of the stone may be a problem for use in asphaltic surface course. Beds of shaly, silty dolostone may require blending with the surrounding, more competent, bedrock units for the production of granular base.

Similar to the Gull River Formation, certain beds within the Bobcaygeon Formation may be alkali-reactive. These beds usually contain up to 3% black chert along with microscopic chalcedony (Rogers 1985). The more shaly, middle parts of the formation may not be as suitable for the production of concrete aggregates as the surrounding strata (D. Williams, MTO, personal communication, 1991). Therefore, selective extraction measures may be required for the production of concrete aggregate from the formation. The formation is generally well suited for most other aggregate uses including asphalt stone and granular base.

SELECTED BEDROCK RESOURCE AREAS

Two areas have been selected for possible bedrock resource protection in Galway and Cavendish Township. The bedrock in these areas is overlain by less than 8 m of overburden and includes the Gull River and Bobcaygeon formations. These bedrock resources are considered valuable since sand and gravel resources are lacking in the township. No specific resources of Precambrian rock have been selected for resource protection because of the wide variations in the quality of these rock types and the presence of Paleozoic limestones which are the preferred sources of crushed stone in the area. However, hard and durable varieties of Precambrian bedrock are the only potential sources of high quality aggregate in some areas in the northern part of the township. A Precambrian bedrock quarry has been opened in this area (quarry no. 1). The importance of the Precambrian rocks, in adding to the township's aggregate resource base, should be recognized.

The Selected Bedrock Resource Areas occupy a total available area of 1600 ha and contain resources of approximately 750 million tonnes.

Selected Bedrock Resource Area 1

Four areas, labelled 1a to 1d on Map 2, make up Selected Bedrock Resource Area 1. Less than 8 m of drift overlies the Gull River Formation in these selected deposits and exposures of bedrock are common. Although the Shadow Lake Formation is also included in these selected areas, it is of poor quality and not suitable for potential extraction. The bedrock of the Shadow Lake Formation outcrops as an extremely thin band along the Precambrian-Paleozoic boundary and, therefore, account for only a very minor portion of the surface area of the Resource Area.

Resource Area 1a forms part of the major body of Paleozoic bedrock which underlies southern Ontario, whereas, Areas 1b to 1d occur as small Paleozoic outliers surrounded by Precambrian bedrock. Although these outliers may be small, they can be locally important sources of aggregate as demonstrated by Area 1d. Quarry no. 3 has been opened in this outlier and the faces revealed 15 to 18 m of the Gull River Formation. The faces consisted predominantly of grey, lithographic limestone with two, 1 to 2 m thick, green, shaly dolostone beds exposed in the middle of the face. MTO has examined the quarry in detail and reports that these green shaly beds, when unweathered, can be blended with the hard and durable, grey limestone beds to produce granular base. The grey limestone is suitable for use as asphalt stone but polishing of the surface stone may be a problem. This limestone should also be tested for alkali-carbonate reactivity before using it for concrete. As chert was observed in the upper 2 m of the quarry face, this rock should be tested for alkali-silica reactivity before using it for concrete. Notwithstanding these quality problems, the stone from the quarry is potentially suitable for the production of a wide range of aggregate products including granular base, asphalt stone and concrete stone with selective extraction measures. The aggregate potentially available in Areas 1a to 1c is expected to be similar to that extracted from quarry no. 3, but detailed subsurface investigation is recommended prior to extraction. A small, inactive building stone quarry (quarry no. 2) is located in Resource Area 1d and faces there exposed 0.6 to 0.9 m of thick- to medium-bedded limestone of the Gull River Formation.

Resource Area 1 occupies 1010 ha. Cultural constraints and previous extraction reduce the area currently available to 980 ha. The thickness of the Gull River Formation can range between 6.1 and 15 m at the Paleozoic escarpment to 24 m near the Bobcaygeon-Gull River formational boundary. At the Paleozoic-Precambrian boundary, the Gull River Formation may be thin and the likelihood of surface exposures of the Shadow Lake Formation increases. Assuming an average workable thickness of 18 m, available bedrock resources are estimated to total 460 million tonnes.

Most of Areas 1a and 1d are readily accessible via the existing road network. A system of recently developed logging trails provide access to Area 1c. Area 1b is currently inaccessible by road.

Selected Bedrock Resource Area 2

Selected Bedrock Resource Area 2 includes Areas 2a to 2c as shown on Map 2. The bedrock in Area 2 is covered by less than 8 m of drift and consists of the Bobcaygeon Formation. It is possible to extract the Bobcaygeon Formation together with the underlying Gull River Formation in areas close to the contact between the two formations. The Bobcaygeon Formation bedrock is generally suitable for uses including granular base, hot-laid asphalt and surface treatment aggregate. Selective extraction may be required for the production of concrete aggregates.

Selected Resource Area 2 occupies 590 ha, of which 540 ha are considered currently available for extraction. Assuming a workable thickness of 18 m, bedrock resources are estimated to be 255 million tonnes. The Resource Area is readily accessible via Highway 121.

SUMMARY

The sand and gravel deposits in Galway and Cavendish Township are the product of glacial activity which occurred during the Late Wisconsinan Substage of the Pleistocene Epoch. Nine of these deposits have been selected for resource protection at the primary and secondary levels of significance. These deposits contain locally important resources of predominantly low-specification aggregate in a township that is generally lacking sand and gravel. A significant proportion of the township's demand for aggregate is currently being met by importing suitable materials from surrounding townships.

Paleozoic limestones are the major potential sources of high quality, crushed stone within the township. These resources lie within two Selected Bedrock Resource Areas in the southern part of the township. The Resource Areas consist of rock of the Gull River and Bobcaygeon formations. These bedrock formations are suitable for a wide range of aggregate applications. Elsewhere in the township, hard and durable varieties of Precambrian bedrock are alternate potential sources of crushed stone. In local areas, however, the Precambrian bedrock surface is deeply weathered and friable and unsuitable for high quality, crushed stone use. This bedrock is weathered to such a degree that it resembles coarse sand and this material has been extracted for the production of low-specification aggregate.

Enquiries regarding the Aggregate Resources Inventory of Galway and Cavendish Township should be directed to the Aggregate Assessment Office, Sedimentary and Environmental Geoscience Section, Ontario Geological Survey, 7th Floor, 77 Grenville Street, Toronto, Ontario, M7A 1W4 [Tel: (416) 965-1663], or to the Resident Geologist, Ministry of Northern Development and Mines, Bag Service 43, Old Troy Road, Tweed, Ontario, K0K 3J0 [Tel: (613) 478-3161], or to the Minden District, Ministry of Natural Resources, Minden, Ontario, K0M 2K0 [Tel: (705) 286-1521].

TABLE 1. TOTAL SAND AND GRAVEL RESOURCES, GALWAY AND CAVENDISH TOWNSHIP.*

1 CLASS NO.	2 DEPOSIT TYPE (*see* Appendix C)	3 AREAL EXTENT Hectares	4 ORIGINAL TONNAGE Millions of Tonnes
2	G–E	2.0	0.2
	G–IC	5.0	0.4
	S–IC	16	1.3
3	S–IC	5.0	0.2
	S–LP	595	24
	S–LP–OW	85	3.6
	S–OW	57	2.4
	S–OW–LP	143	5.0
	S–SF	13	0.6
4	S–LP	465	9.0
	S–OW	21	0.4
	S–OW–LP	19	0.3
TOTAL FOR REPORT AREA:		1430	47

N.B. Minor variations in all tables are caused by rounding of data.

* *Identified deposit areas within Kawartha Highlands Provincial Park are omitted on all tables.*

TABLE 2. SAND AND GRAVEL PITS, GALWAY AND CAVENDISH TOWNSHIP.

1 NO.	2 MTO NO.	3 FACE HEIGHT Metres	4 % GRAVEL	5 REMARKS
1	M20–26	–	–	no access
2	–	0.9–1.5	10–30	recent extraction, water on pit floor
3	–	0.9–1.5	10–15	medium to coarse sand, minor gravel units, water on pit floor
4	–	0.9–1.2	–	mainly sand, overgrown, water on pit floor
5	–	1.5–2.4	–	weathered bedrock
6	–	1.5–3.0	–	weathered bedrock
7	–	1.8	–	silty fine to medium sand
8	–	1.5–2.4	–	silty fine sand over bedrock
9	–	1.5–2.4	–	silty fine sand over bedrock
10	F6–5	1.5–4.5	40–50	medium to coarse gravel, bedrock in pit floor, silt and clay overlies gravel in one face, near depletion
11	–	2.4–6.1	5–25	recent extraction
12	–	< 1.5	–	weathered bedrock
13	–	1.5–3.0	–	weathered bedrock
14	–	1.5–3.0	–	bedrock in pit floor, depleted
15	–	1.5–3.0	0–30	mainly fine sand, pockets of sandy fine to medium gravel, abundant weathered clasts, water on pit floor
16	G3–71	6.1	–	till
17	–	< 1.5	–	weathered bedrock
18	–	0.5–1.0	–	weathered bedrock, overgrown
19	–	1.2–1.8	–	weathered bedrock
20	G3–65	1.5	–	weathered bedrock
21	–	1.5–3.0	–	weathered bedrock
22	–	1.5	–	weathered bedrock
23	–	1.5	–	weathered bedrock
24	–	1.5	–	weathered bedrock, depleted
25	–	1.5	–	weathered bedrock
26	–	1.5–3.0	–	weathered bedrock
27	–	1.5	–	weathered bedrock
28	–	4.6	–	till, slumped
29	–	1.5	–	mainly fine gravelly sand, water on pit floor
30	–	1.5–2.5	–	sandy gravel over silty fine sand, slumped faces, water on pit floor
31	–	< 1.5	–	weathered bedrock

TABLE 3. SELECTED SAND AND GRAVEL RESOURCE AREAS, GALWAY AND CAVENDISH TOWNSHIP.

1 DEPOSIT NO.	2 AREA Hectares	3 CULTURAL SETBACKS Hectares	4 EXTRACTED AREA Hectares	5 AVAILABLE AREA Hectares	6 ESTIMATED DEPOSIT THICKNESS Metres	7 AVAILABLE AGGREGATE Millions of Tonnes
1	16	0	1.0	15	4.6	1.2

TABLE 4. TOTAL IDENTIFIED BEDROCK RESOURCES, GALWAY AND CAVENDISH TOWNSHIP.

1 DRIFT THICKNESS Metres	2 FORMATION	3 ESTIMATED DEPOSIT THICKNESS Metres	4 AREAL EXTENT Hectares	5 ORIGINAL TONNAGE Millions of Tonnes
0–1	Gull River & Shadow Lake	18	640	300
1–8	Gull River & Shadow Lake	18	370	173
			1010	475
0–1	Bobcaygeon	18	290	136
1–8	Bobcaygeon	18	300	140
			590	275
TOTAL FOR REPORT AREA:			1600	750

TABLE 5. QUARRIES, GALWAY AND CAVENDISH TOWNSHIP.

1 NO.	2 MTO NO.	3 FACE HEIGHT Metres	4 REMARKS
1	G3-79	6.1–7.6	Precambrian granitic rock
2	B9-41	0.6–0.9	abandoned building stone quarry, Gull River Formation
3	B9-9	15–18	Gull River Formation

TABLE 6. SELECTED BEDROCK RESOURCE AREAS, GALWAY AND CAVENDISH TOWNSHIP.

1 **DEPOSIT NO.**	2 **DEPTH OF OVERBURDEN** Metres	3 **AREA** Hectares	4 **CULTURAL SETBACKS** Hectares	5 **EXTRACTED AREA** Hectares	6 **AVAILABLE AREA** Hectares	7 **ESTIMATED WORKABLE THICKNESS** Metres	8 **AVAILABLE RESOURCES** Millions of Tonnes
1a	0–8	880	30	0	850	18	398
1b	0–1	27	0	0	27	18	13
1c	0–1	65	0	0	65	18	30
1d	0–1	41	0	1	40	18	19
		1010	30	1	980		460
2a	0–8	21	13	0	8	18	4
2b	0–8	425	30	0	395	18	185
2c	0–8	140	0	0	140	18	66
		590	43	0	540		255
TOTAL FOR REPORT AREA:		1600	73	1	1520		720

TABLE 7. SUMMARY OF TEST HOLE DATA, GALWAY AND CAVENDISH TOWNSHIP.

- N O N E -

TABLE 8. SUMMARY OF GEOPHYSICS DATA, GALWAY AND CAVENDISH TOWNSHIP.

- N O N E -

TABLE 9. RESULTS OF AGGREGATE QUALITY TESTS, GALWAY AND CAVENDISH TOWNSHIP.

- N O N E -

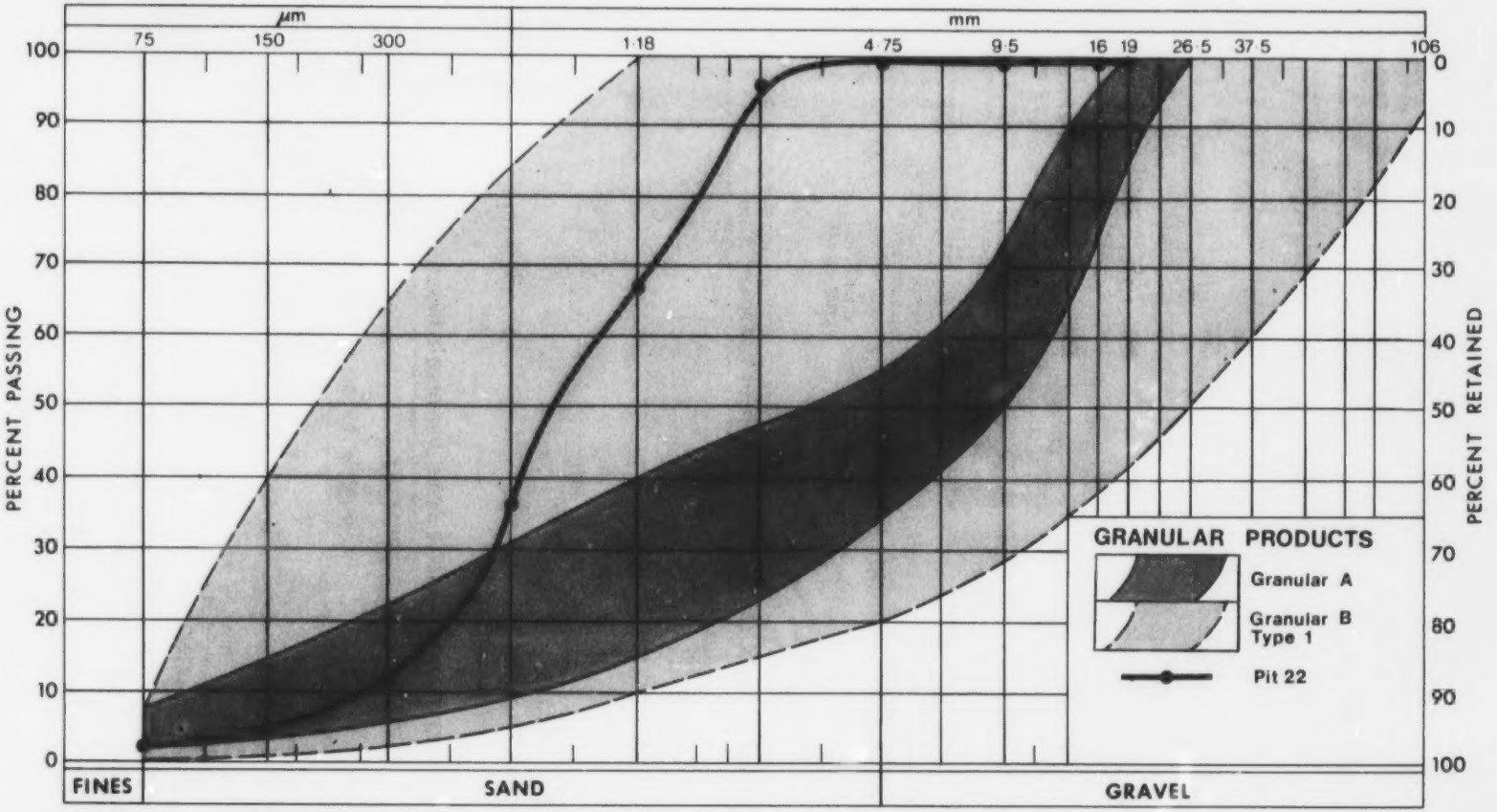


FIGURE 3a. AGGREGATE GRADING CURVES, GALWAY AND CAVENDISH TOWNSHIP.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from Ontario Provincial Standard Specifications OPSS 1010, 1988).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

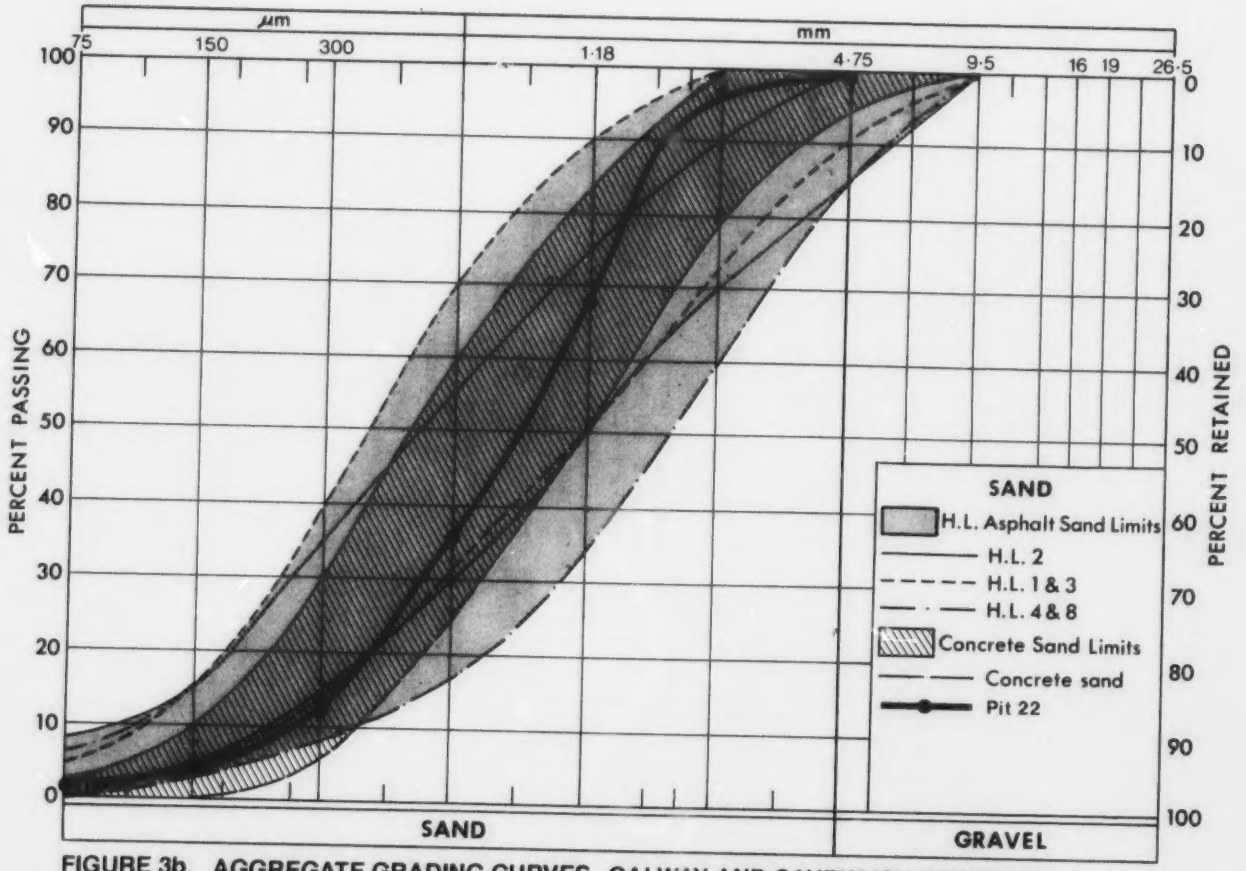


FIGURE 3b. AGGREGATE GRADING CURVES, GALWAY AND CAVENDISH TOWNSHIP.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from Ontario Provincial Standards Specifications OPSS 1002, 1988 and 1003, 1988).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample taken at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

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Appendix B — Glossary

Abrasion Resistance: Tests such as the Los Angeles abrasion test are used to measure the ability of aggregate to resist crushing and pulverizing under conditions similar to those encountered in processing and use. Measuring resistance is an important component in the evaluation of the quality and prospective uses of aggregate. Hard, durable material is preferred for road building.

Absorption Capacity: Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate.

Aggregate: Any hard, inert, construction material (sand, gravel, shells, slag, crushed stone or other mineral material) used for mixing in various-sized fragments with a cement or bituminous material to form concrete, mortar, etc., or used alone for road building or other construction. Synonyms include mineral aggregate and granular material.

Aggregate Abrasion Value: This test directly measures the resistance of aggregate to abrasion with silica sand and a steel disk. The higher the value, the lower the resistance to abrasion. For high quality asphalt surface course uses, values of less than 6 are desirable.

Alkali-aggregate Reaction: A chemical reaction between the alkalies of Portland cement and certain minerals found in rocks used for aggregate. Alkali-aggregate reactions are undesirable because they can cause expansion and cracking of concrete. Although perfectly suitable for building stone and asphalt applications, alkali-reactive aggregates should be avoided for structural concrete uses.

Beneficiation: Beneficiation of aggregates is a process or combination of processes which improves the quality (physical properties) of a mineral aggregate and is not part of the normal processing for a particular use, such as routine crushing, screening, washing or classification. Heavy media separation, jigging or application of special crushers (e.g., "cage mill") are usually considered processes of beneficiation.

Blending: Required in cases of extreme coarseness, fineness or other irregularities in the gradation of unprocessed aggregate. Blending is done with approved sand-sized aggregate in order to satisfy the gradation requirements of the material.

Bulk Relative Density: An aggregate with low relative density is lighter in weight than one with a high relative density. Low relative density aggregates (less than about 2.5) are often nondurable for many aggregate uses.

Cambrian: The first period of the Paleozoic Era, thought to have covered the time between 570 and 500 million years ago. The Cambrian precedes the Ordovician Period.

Clast: An individual constituent, grain or fragment of a sediment or rock, produced by the mechanical weathering of a larger rock mass. Synonyms include particle and fragment.

Crushable Aggregate: Unprocessed gravel containing a minimum of 35% coarse aggregate larger than the No. 4 sieve (4.75 mm) as well as a minimum of 20% greater than the 26.5 mm sieve.

Deleterious Lithology: A general term used to designate those rock types which are chemically or physically unsuited for use as construction or road-building aggregates. Such lithologies as chert, shale, siltstone and sandstone may deteriorate rapidly when exposed to traffic and other environmental conditions.

Devonian: A period of the Paleozoic Era thought to have covered the span of time between 395 and 345 million years ago, following the Silurian Period. Rocks formed in the Devonian Period are among the youngest found in Ontario.

Dolostone: A carbonate sedimentary rock consisting chiefly of the mineral dolomite and containing relatively little calcite (dolostone is also known as dolomite).

Drift: A general term for all unconsolidated rock debris transported from one place and deposited in another, distinguished from underlying bedrock. In North America, glacial activity has been the dominant mode of transport and deposition of drift. Synonyms include overburden and surficial deposit.

Drumlin: A low, smoothly rounded, elongated hill, mound or ridge composed of glacial materials. These landforms were formed beneath an advancing ice sheet, and were shaped by its flow.

Eolian: Pertaining to the wind, especially with respect to landforms whose constituents were transported and deposited by wind activity. Sand dunes are an example of an eolian landform.

Fines: A general term used to describe the size fraction of an aggregate which passes (is finer than) the No. 200 mesh screen (0.075 mm). Also described informally as "dirt", these particles are in the silt and clay size range.

Glacial Lobe: A tongue-like projection from the margin of the main mass of an ice cap or ice sheet. During the Pleistocene Epoch several lobes of the Laurentide continental ice sheet occupied the Great Lakes basins. These lobes advanced then melted back numerous times during the Pleistocene, producing the complex arrangement of glacial landforms found in Ontario.

Gneiss: A coarse-textured metamorphic rock with the minerals arranged in parallel streaks or bands. Gneiss is relatively rich in feldspar. Other common minerals found in this rock include quartz, mica, amphibole and garnet.

Gradation: The proportion of material of each particle size, or the frequency distribution of the various sizes

which constitute a sediment. The strength, durability, permeability and stability of an aggregate depend to a great extent on its gradation. The size limits for different particles are as follows:

Boulder	more than 200 mm
Cobbles	75-200 mm
Coarse Gravel	26.5-75 mm
Fine Gravel	4.75-26.5 mm
Coarse Sand	2-4.75 mm
Medium Sand	0.425-2 mm
Fine Sand	0.075-0.425 mm
Silt, Clay	less than 0.075 mm

Granite: A coarse-grained, light-coloured rock that ordinarily has an even texture and is composed of quartz and feldspar with either mica, hornblende or both.

Granular Base and Subbase: Components of a pavement structure of a road, which are placed on the subgrade and are designed to provide strength, stability and drainage, as well as, support for surfacing materials. Four types have been defined: Granular A consists of crushed and processed aggregate and has relatively stringent quality standards in comparison to Granular B which is usually pit-run or other unprocessed aggregate, Granular M is a shouldering and surface dressing material with quality requirements similar to Granular A, and Select Subgrade Material has similar quality requirements to Granular B and it provides a stable platform for the overlying pavement structure. (For more specific information the reader is referred to Ontario Provincial Standard Specification OPSS 1010).

Hot-laid (or Asphaltic) Aggregate: Bituminous, cemented aggregates used in the construction of pavements either as surface or bearing course (HL 1, 3 and 4), or as binder course (HL 2 and 8) used to bind the surface course to the underlying granular base.

Lithology: The description of rocks on the basis of such characteristics as colour, structure, mineralogic composition and grain size. Generally, the description of the physical character of a rock.

Los Angeles Abrasion and Impact Test: This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium Sulphate Soundness Test: This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates which are susceptible to freezing and thawing will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Meltwater Channel: A drainage way, often terraced, produced by water flowing away from a melting glacier margin.

Ordovician: An early period of the Paleozoic Era thought to have covered the span of time between 500 and 435 million years ago.

Paleozoic Era: One of the major divisions of the geologic time scale thought to have covered the time between 570 and 230 million years ago, the Paleozoic Era (or Ancient Life Era) is subdivided into six geologic periods, of which only four (Cambrian, Ordovician, Silurian and Devonian) can be recognized in southern Ontario.

Petrographic Examination: An aggregate quality test based on known field performance of various rock types. In Ontario the test result is a Petrographic Number (PN). The higher the PN, the lower the quality of the aggregate.

Pleistocene: An epoch of the recent geological past including the time from approximately 2 million years ago to 7000 years ago. Much of the Pleistocene was characterized by extensive glacial activity and is popularly referred to as the "Great Ice Age".

Polished Stone Value: This test measures the frictional properties of aggregates after 6 hours of abrasion and polishing with an emery abrasive. The higher the PSV, the higher the frictional properties of the aggregate. Values less than 45 indicate marginal frictional properties, while values greater than 55 indicate excellent frictional properties.

Possible Resource: Reserve estimates based largely on broad knowledge of the geological character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on assumed continuity or repetition for which there are reasonable geological indications.

Precambrian: The earliest geological period extending from the consolidation of the earth's crust to the beginning of the Cambrian.

Shale: A fine-grained, sedimentary rock formed by the consolidation of clay, silt or mud and characterized by well developed bedding planes, along which the rock breaks readily into thin layers. The term shale is also commonly used for fissile claystone, siltstone and mudstone.

Silurian: An early period of the Palezoic Era thought to have covered the time between 435 and 395 million years ago. The Silurian follows the Ordovician Period and precedes the Devonian Period.

Soundness: The ability of the components of an aggregate to withstand the effects of various weathering processes and agents. Unsound lithologies are subject to disintegration caused by the expansion of absorbed solutions. This may seriously impair the performance of road-building and construction aggregates.

Till: Unsorted and unstratified rock debris, deposited directly by glaciers and ranging in size from clay to large boulders.

Wisconsinan: Pertaining to the last glacial period of the Pleistocene Epoch in North America. The Wisconsinan began approximately 100 000 years ago and ended approximately 7000 years ago. The glacial deposits and landforms of southern Ontario are predominantly the result of glacial activity during the Wisconsinan Stage.

Appendix C — Geology of Sand and Gravel Deposits

The type, distribution, and extent of sand and gravel deposits in Ontario are the result of extensive glacial and glacially influenced activity in Wisconsinan time during the Pleistocene Epoch, approximately 100 000 to 7000 years ago. The deposit types reflect the different depositional environments that existed during the melting and retreat of the continental ice masses and can readily be differentiated on the basis of their morphology, structure and texture. The deposit types are described below.

GLACIOFLUVIAL DEPOSITS

These deposits can be divided into two broad categories: those that were formed in contact with (or in close proximity to) glacial ice and those that were deposited by meltwaters carrying materials beyond the ice margin.

Ice-Contact Terraces (ICT) These are glaciofluvial features deposited between the glacial margin and a confining topographic high, such as the side of a valley. The structure of the deposits may be similar to that of outwash deposits, but in most cases the sorting and grading of the material is more variable and the bedding is discontinuous because of extensive slumping. The probability of locating large amounts of crushable aggregate is moderate and extraction may be expensive because of the variability of the deposits both in terms of quality and grain size distribution.

Kames (K) Kames are defined as mounds of poorly sorted sand and gravel deposited by meltwater in depressions or fissures on the ice surface or at its margin. During glacial retreat, the melting of supporting ice causes collapse of the deposits, producing internal structures characterized by bedding discontinuities. The deposits consist mainly of irregularly bedded and crossbedded, poorly sorted sand and gravel. The present forms of the deposits include single mounds, linear ridges (crevasse fillings) or complex groups of landforms. The latter are occasionally described as "undifferentiated ice-contact stratified drift" (IC) when detailed subsurface information is unavailable. Since kames commonly contain large amounts of fine-grained material and are characterized by considerable variability, there is generally a low to moderate probability of discovering large amounts of good quality, crushable aggregate. Extractive problems encountered in these deposits are mainly the excessive variability of the aggregate and the rare presence of excess fines (silt- and clay-sized particles).

Eskers (E) Eskers are narrow, sinuous ridges of sand and gravel deposited by meltwaters flowing in tunnels within or at the base of glaciers, or in channels on the ice surface. Eskers vary greatly in size. Many, though not all eskers, consist of a central core of poorly sorted and stratified gravel characterized by a wide range in grain size. The core material is often draped on its flanks by better sorted and stratified sand and gravel. The deposits have a high probability of containing a large proportion of crushable aggregate and since they are generally built above the surrounding ground surface, are convenient extraction sites. For these reasons esker deposits have been traditional aggregate sources throughout Ontario and are significant components of the total resources of many areas.

Some planning constraints and opportunities are inherent in the nature of the deposits. Because of their linear nature, the deposits commonly extend across several property boundaries leading to unorganized extractive development at numerous small pits. On the other hand, because of their form, eskers can be easily and inexpensively extracted and are amenable to rehabilitation and sequential land use.

Undifferentiated Ice-Contact Stratified Drift (IC) This designation may include deposits from several ice-contact, depositional environments which usually form extensive, complex landforms. It is not feasible to identify individual areas of coarse-grained material within such deposits because of their lack of continuity and grain size variability. They are given a qualitative rating based on existing pit and other subsurface data.

Outwash (OW) Outwash deposits consist of sand and gravel laid down by meltwaters beyond the margin of the ice lobes. The deposits occur as sheets or as terraced valley fills (valley trains) and may be very large in extent and thickness. Well developed outwash deposits have good horizontal bedding and are uniform in grain size distribution. Outwash deposited near the glacier's margin is much more variable in texture and structure. The probability of locating useful crushable aggregates in outwash deposits is moderate to high depending on how much information on size, distribution and thickness is available.

Subaqueous Fan (SF) Subaqueous fans are formed within or near the mouths of meltwater conduits when sediment-laden meltwaters are discharged into a standing body of water. The geometry of the resulting deposit is fan- or lobe-shaped. Several of these lobes may be joined together to form a larger, continuous sedimentary body. Internally, subaqueous fans consist of stratified sands and gravels which may exhibit wide variations in grain size distribution. As these features were deposited under glacial lake waters, silt and clay which settled out of these lakes may be associated in varying amounts with these deposits. The variability of the sediments and presence of fines are the main extractive problems associated with these deposits.

Alluvium (AL) Alluvium is a general term for clay, silt, sand, gravel or similar unconsolidated material deposited during postglacial time by a stream as sorted or semi-sorted sediment, on its bed or on its floodplain. The probability of locating large amounts of crushable aggregate in alluvial deposits is low and they have

generally low value because of the presence of excess silt- and clay-sized material. There are few large post-glacial alluvium deposits in Ontario.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine Beach Deposits (LB) These are relatively narrow, linear features formed by wave action at the shores of glacial lakes that existed at various times during the deglaciation of Ontario. Well developed lacustrine beaches are usually less than 6 m thick. The aggregate is well sorted and stratified and sand-sized material commonly predominates. The composition and size distribution of the deposit depends on the nature of the source material. The probability of obtaining crushable aggregate is high when the material is developed from coarse-grained materials such as a stony till and low when developed from fine-grained materials. Beaches are relatively narrow, linear deposits, so that extractive operations are often numerous and extensive.

Glaciolacustrine Deltas (LD) These features were formed where streams or rivers of glacial meltwater flowed into lakes and deposited their suspended sediment. In Ontario, such deposits tend to consist mainly of sand and abundant silt. However, in near-ice and ice-contact positions, coarse material may be present. Although deltaic deposits may be large, the probability of obtaining coarse material is generally low.

Glaciolacustrine Plains (LP) The nearly level surface marking the floor of an extinct glacial lake. The sediments which form the plain are predominantly fine to medium sand, silt and clay and were deposited in relatively deep water. Lacustrine deposits are generally of low value as aggregate sources because of their fine grain size and lack of crushable material. In some aggregate-poor areas, lacustrine deposits may constitute valuable sources of fill and some granular subbase aggregate.

GLACIAL DEPOSITS

End Moraines (EM) These are belts of glacial drift deposited at, and parallel to, glacier margins. End moraines commonly consist of ice-contact stratified drift and in such instances are usually called kame moraines. Kame moraines commonly result from deposition between two glacial lobes (interlobate moraines). The probability of locating aggregates within such features is moderate to low. Exploration and development costs are high. Moraines may be very large and contain vast aggregate resources, but the location of the best areas within the moraine is usually poorly defined.

EOLIAN DEPOSITS

Windblown Deposits (WD) Windblown deposits are those formed by the transport and deposition of sand by winds. The form of the deposits ranges from extensive, thin layers to well developed linear and crescentic ridges known as dunes. Most windblown deposits in Ontario are derived from, and deposited on, pre-existing lacustrine sand plain deposits. Windblown sediments almost always consist of fine to coarse sand and are usually well sorted. The probability of locating crushable aggregate in windblown deposits is very low.

Appendix D — Geology of Bedrock Deposits

The purpose of this appendix is to familiarize the reader with the general bedrock geology of southern Ontario (Figure D1), and the potential uses of the various bedrock formations where known. The reader is cautioned against using this information for more specific purposes. The stratigraphic chart (Figure D2) is intended only to illustrate the stratigraphic sequences in particular geographic areas and should not be used as a regional correlation table.

The following description is arranged in ascending stratigraphic order, on a group and formation basis. Precambrian rocks are not discussed. Additional stratigraphic information is included for some formations where necessary. The publications and maps of the Ontario Geological Survey and the Geological Survey of Canada should be referred to for more detailed information. The composition, thickness and uses of the formations are discussed. If a formation may be suitable for use as aggregate and aggregate suitability test data is available, the data has been included in the form of ranges. The following short forms have been used in presenting this data: PSV = Polished Stone Value, AAV = Aggregate Abrasion Value, $MgSO_4$ = Magnesium Sulphate Soundness Test (loss in percent), LA = Los Angeles Abrasion and Impact Test (loss in percent), Absn = Absorption (percent), BRD = Bulk Relative Density, PN (Asphalt & Concrete) = Petrographic Number for Asphalt and Concrete use.

The ranges are intended as a guide only and care should be exercised in extrapolating the information to specific situations. Aggregate suitability test data has been provided by the Ontario Ministry of Transportation.

Covey Hill Formation (Cambrian)

STRATIGRAPHY: lower formation of the Potsdam Group. COMPOSITION: interbedded noncalcareous feldspathic conglomerate and sandstone. THICKNESS: 0 to 14 m. USES: has been quarried for aggregate in South Burgess Township, Leeds County.

Nepean Formation (Cambro-Ordovician)

STRATIGRAPHY: upper formation of the Potsdam Group. COMPOSITION: thin-bedded to massive quartz sandstone with some conglomerate interbeds and rare shaly partings. THICKNESS: 0 to 30 m. USES: suitable as dimension stone; quarried at Philipsville and Forfar for silica sand; alkali-silica reactive in Portland cement concrete. AGGREGATE SUITABILITY TESTING: PSV = 54-68, AAV = 4-15, $MgSO_4$ = 9-32, LA = 44-90, Absn = 1.6-2.6, BRD = 2.38-2.50, PN (Asphalt & Concrete) = 130-140.

March Formation (Lower Ordovician)

STRATIGRAPHY: lower formation of the Beekmantown Group. COMPOSITION: interbedded quartz sandstone, dolomitic quartz sandstone, sandy dolostone and dolostone. THICKNESS: 18 to 60 m. USES: quarried extensively for aggregate in area of subcrop and outcrop; alkali-silica reactive in Portland cement concrete; lower part of formation is an excellent source of skid-resistant aggregate; suitable for use as facing stone and paving stone. AGGREGATE SUITABILITY TESTING: PSV = 55-60, AAV = 4-6, $MgSO_4$ = 1-17, LA = 15-38, Absn = 0.5-0.9, BRD = 2.61-2.65, PN (Asphalt & Concrete) = 110-150.

Oxford Formation (Lower Ordovician)

STRATIGRAPHY: upper formation of the Beekmantown Group. COMPOSITION: thin- to thick-bedded, microcrystalline to medium-crystalline, grey dolostone with thin shaly interbeds. THICKNESS: 61 to 102 m. USES: quarried in the Brockville and Smith Falls areas and south of Ottawa for use as aggregate. AGGREGATE SUITABILITY TESTING: PSV = 47-48, AAV = 7-8, $MgSO_4$ = 1-4, LA = 18-23, Absn = 0.7-0.9, BRD = 2.74-2.78, PN (Asphalt & Concrete) = 105-120.

Rockcliffe Formation (Middle Ordovician)

STRATIGRAPHY: divided into lower member and upper (St. Martin) member. COMPOSITION: interbedded quartz sandstone and shale; interbedded shaly bioclastic limestone and shale predominating in upper member to the east. THICKNESS: 0 to 125 m. USES: upper member has been quarried east of Ottawa for aggregate; lower member has been used as crushed stone; some high purity limestone beds in upper member may be suitable for use as fluxing stone and in lime production. AGGREGATE SUITABILITY TESTING: PSV = 58-63, AAV = 10-11, $MgSO_4$ = 12-40, LA = 25-28, Absn = 1.8-1.9, BRD = 2.55-2.62, PN (Asphalt & Concrete) = 122-440.

Shadow Lake Formation (Middle Ordovician)

STRATIGRAPHY: eastern Ontario - the basal unit of the Ottawa Group; central Ontario - overlain by the Simcoe Group. COMPOSITION: in eastern Ontario - silty and sandy dolostone with shale partings and minor interbeds of sandstone; in central Ontario -

conglomerates, sandstones and shales. THICKNESS: eastern Ontario - 2 to 3 m; central Ontario - 0 to 12 m. USES: potential source of decorative stone; very limited value as aggregate source.

Gull River Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and Ottawa Group (eastern Ontario). In central and eastern Ontario the formation is subdivided into upper and lower members; west of Lake Simcoe it is presently subdivided into upper, middle and lower members. COMPOSITION: in central and eastern Ontario, the lower member consists of alternating units of limestone, dolomitic limestone and dolostone, the upper member consists of thin-bedded limestones with thin shale partings; west of Lake Simcoe, the lower member is thin- to thick-bedded, interbedded, grey argillaceous limestone and buff to green dolostone, whereas the upper and middle members are dense microcrystalline limestones with argillaceous dolostone interbeds. THICKNESS: 7 to 62 m. USES: quarried in the Lake Simcoe, Kingston, Ottawa and Cornwall areas for crushed stone; rock from certain layers in eastern and central Ontario has proven to be alkali-reactive when used in Portland cement concrete (alkali-carbonate reaction). AGGREGATE SUITABILITY TESTING: PSV = 41-49, AAV = 8-12, $MgSO_4$ = 3-13, LA = 18-28, Absn = 0.3-0.9, BRD = 2.68-2.73, PN (Asphalt & Concrete) = 100-153.

Bobcaygeon Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and the Ottawa Group (eastern Ontario), subdivided into upper, middle and lower members; members in eastern and central Ontario are approximately equivalent. COMPOSITION: homogeneous, massive to thin-bedded fine-crystalline limestone with numerous shaly partings in the middle member. THICKNESS: 24 to 87 m. USES: quarried at Brechin, Marysville and in the Ottawa area for crushed stone; generally suitable for use as granular base aggregate; rock from certain layers has been found to be alkali-reactive when used in Portland cement concrete (alkali-silica reaction). AGGREGATE SUITABILITY TESTING: PSV = 47-51, AAV = 14-23, $MgSO_4$ = 1-40, LA = 18-32, Absn = 0.3-2.4, BRD = 2.5-2.69, PN (Asphalt & Concrete) = 100-320.

Verulam Formation (Middle Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa groups. COMPOSITION: fossiliferous, pure to argillaceous limestone interbedded with calcareous shale. THICKNESS: 32 to 70 m. USES: quarried at Picton and Bath for use in cement manufacture; quarried for aggregate in Mara Township, Simcoe County and in the Belleville-Kingston area; may be unsuitable for use as aggregate in some areas because of its high shale content. AGGREGATE SUITABILITY TESTING: PSV = 43-44, AAV = 9-13, $MgSO_4$ = 4-45, LA = 22-29, Absn = 0.4-2.1, BRD = 2.59-2.70, PN (Asphalt & Concrete) = 120-255.

Lindsay Formation (Middle and Upper Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa groups; in eastern Ontario is divisible into an unnamed lower member and the Eastview Member; in central Ontario is divisible into the Collingwood Member (equivalent to portions of the Eastview Member) and a lower member. COMPOSITION: in eastern Ontario, the lower member is interbedded, very fine- to coarse-crystalline limestone with undulating shale partings and interbeds of dark grey calcareous shale, whereas the Eastview Member is an interbedded dark grey to dark brown calcareous shale and very fine- to fine-crystalline, petroliferous limestone; in central Ontario, Collingwood Member is a black, calcareous shale whereas the lower member is a very fine- to coarse-crystalline, thin-bedded limestone with very thin, undulating shale partings. THICKNESS: 25 to 61 m. USES: in eastern Ontario, the lower member is used extensively for aggregate production; in central Ontario, it is quarried at Picton, Ogden Point and Bowmanville for cement; may be suitable or unsuitable for use as concrete and asphalt aggregate. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 2-47, LA = 20-28, Absn = 0.4-1.3, BRD = 2.64-2.70, PN (Asphalt & Concrete) = 110-215.

Blue Mountain and Billings Formations (Upper Ordovician)

STRATIGRAPHY: central Ontario - Blue Mountain Formation includes the upper and middle members of the former Whitby Formation; eastern Ontario - Billings Formation is equivalent to part of the Blue Mountain Formation. COMPOSITION: the Blue Mountain Formation is blue-grey, noncalcareous shale; Billings Formation is dark grey to black, noncalcareous to slightly calcareous, pyritiferous shale with dark grey limestone laminae and grey siltstone interbeds. THICKNESS: Blue Mountain Formation - 43 to 61 m; Billings Formation - 0 to 62 m. USES: Billings Formation may be a suitable source for structural clay products and expanded aggregate; Blue Mountain Formation may be suitable for structural clay products.

Georgian Bay and Carlsbad Formations (Upper Ordovician)

COMPOSITION: in central Ontario, the Georgian Bay Formation is composed of interbedded limestone and shale; in eastern Ontario, the Carlsbad Formation is composed of interbedded shale, siltstone and bioclastic limestone; THICKNESS: Georgian Bay Formation - 91 to 170 m; Carlsbad Formation - 0 to 186 m. USES: Georgian Bay Formation is used by several producers in Metropolitan Toronto area to produce brick and structural tile, as well as for making Portland cement; at

Streetsville, expanded shale was used in the past to produce lightweight aggregate; Carlsbad Formation is used as a source material for brick and tile manufacturing, has potential as a lightweight expanded aggregate.

Queenston Formation (Upper Ordovician)

COMPOSITION: red, thin- to thick-bedded, sandy to argillaceous shale with green mottling and banding. THICKNESS: 122 to 152 m. USES: there are several large quarries developed in the Queenston Formation in the Toronto-Hamilton region and one at Russell, near Ottawa; all extract shale for brick manufacturing; the Queenston Formation is the most important source material for brick manufacture in Ontario.

Whirlpool Formation (Lower Silurian)

STRATIGRAPHY: lower formation in the Cataract Group in the Niagara Penninsula and the Niagara Escarpment as far north as Duntroon. COMPOSITION: massive, medium- to coarse-grained, argillaceous white to light grey quartz sandstone with thin grey shale partings. THICKNESS: 0 to 8 m. USES: building stone, flagstone.

Manitoulin Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs north of Stoney Creek. COMPOSITION: thin-bedded, blue-grey to buff brown dolomitic limestones and dolostones. THICKNESS: 0 to 23 m. USES: extracted for crushed stone in St. Vincent Township, Grey County, and for decorative stone on Manitoulin Island. AGGREGATE SUITABILITY TESTING: no data.

Cabot Head Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs throughout southern Ontario, south and north of the Niagara Escarpment. COMPOSITION: green, grey and red shales. THICKNESS: 15 to 18 m; USES: potential source of coated lightweight aggregate and raw material for use in manufacture of brick and tile; lack of suitable exposures has limited its use.

Grimsby Formation

STRATIGRAPHY: upper formation of the Cataract Group, is identified on the Niagara Peninsula as far north as Clappison's Corners. COMPOSITION: interbedded sandstone and shale, mostly red. THICKNESS: 0 to 15 m. USES: no present uses.

Thorold Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on the Niagara Peninsula. COMPOSITION: thick-bedded quartz sandstone. THICKNESS: 2 to 3 m. USES: no present uses.

Neagha Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on the Niagara Peninsula. COMPOSITION; dark grey to green shale with minor interbedded limestone. THICKNESS: 0 to 2 m. USES: no present uses.

Dyer Bay Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: highly fossiliferous, impure dolostone. THICKNESS: 0 to 6 m. USES: no present uses.

Wingfield Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: olive green to grey shale with dolostone interbeds. THICKNESS: 0 to 11 m. USES: no present uses.

St. Edmund Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula, upper portion previously termed the Mindemoya Formation. COMPOSITION: pale grey to buff brown, micro- to medium-crystalline, thin- to medium-bedded dolostone. THICKNESS: 0 to 26 m. USES: quarried for fill and crushed stone on Manitoulin Island. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-2, LA = 19-21, Absn = 0.6-0.7, BRD = 2.78-2.79, PN (Asphalt & Concrete) = 105.

Fossil Hill and Reynales Formations (Middle Silurian)

STRATIGRAPHY: part of Clinton Group; Fossil Hill Formation occurs in the northern part of the Niagara Escarpment and is approximately equivalent in part, to the Reynales Formation which occurs on the Niagara Peninsula and the Escarpment, as far north as the Forks of the Credit. COMPOSITION: Fossil Hill Formation is fine- to coarse-crystalline dolostone with high silica content; Reynales Formation is thin- to thick-bedded shaly dolostone and dolomitic limestone. THICKNESS: Fossil Hill Formation - 6 to 26 m; Reynales Formation - 0 to 3 m. USES: both formations quarried for aggregate with overlying Amabel and Lockport Formations. AGGREGATE SUITABILITY TESTING: (Fossil Hill Formation on Manitoulin Island) $MgSO_4$ = 41, LA = 29, Absn = 4.1, BRD = 2.45, PN (Asphalt & Concrete) = 370.

Irondequoit Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group on the Niagara Peninsula south of Waterdown. COMPOSITION: massive, coarse-crystalline crinoidal limestone. THICKNESS: 0 to 2 m. USES: not significantly utilized.

Rochester Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group along the Niagara Peninsula. COMPOSITION: black to dark grey

calcareous shale with numerous limestone lenses. THICKNESS: 5 to 18 m. USES: not significantly utilized. AGGREGATE SUITABILITY TESTING: PSV = 69, AAV = 17, $MgSO_4$ = 95, LA = 19, Absn = 2.2, BRD = 2.67, PN (Asphalt & Concrete) = 400.

Decew Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group south of Waterdown along the Niagara Peninsula. COMPOSITION: sandy to shaly dolomitic limestone and dolostone. THICKNESS: 0 to 5 m. USES: too shaly for high quality uses, but is quarried along with Lockport Formation in places. AGGREGATE SUITABILITY TESTING: PSV = 67, AAV = 15, $MgSO_4$ = 55, LA = 21, Absn = 2.2, BRD = 2.66, PN (Asphalt & Concrete) = 255.

Lockport and Amabel Formations (Middle Silurian)

STRATIGRAPHY: Lockport Formation occurs from Waterdown to Niagara Falls, subdivided into 3 formal members: Gasport, Goat Island and Eramosa members and an informal member (the "Vinemount shale beds"); the stratigraphically equivalent Amabel Formation, found from Waterdown to Cockburn Island, is subdivided into Lions Head, Wiarton/Colpoy Bay and Eramosa members. COMPOSITION: Lockport Formation is thin- to massive-bedded, fine- to medium-crystalline dolostone; Amabel Formation is thin-bedded to massive, medium-crystalline dolostone with reef facies near Georgetown and on the Bruce Peninsula. THICKNESS: Lockport/ Amabel - 3 to 40 m. USES: both formations have been used to produce lime, crushed stone, concrete aggregate and building stone throughout their area of occurrence, and are a resource of provincial significance. AGGREGATE SUITABILITY TESTING: PSV = 36-49, AAV = 10-17, $MgSO_4$ = 2-6, LA = 25-32, Absn = 0.4-1.54, BRD = 2.61-2.81, PN (Asphalt & Concrete) = 100-105.

Guelph Formation (Middle Silurian)

STRATIGRAPHY: exposed on the Niagara Escarpment from the Niagara River to the tip of the Bruce Peninsula, mostly present in the subsurface of southwestern Ontario. COMPOSITION: microcrystalline to medium-crystalline, thick-bedded, soft, porous dolostone, characterized in places by extensive vuggy, porous reefal facies of high chemical purity. THICKNESS: 30 to 52 m. USES: some areas appear soft and unsuitable for use in the production of load-bearing aggregate; this unit requires additional testing to fully establish its aggregate suitability; main use is for dolomitic lime for cement manufacture; quarried near Hamilton and Guelph.

Salina Formation (Upper Silurian)

STRATIGRAPHY: present in the subsurface of southwestern Ontario; rarely exposed at the surface. COMPOSITION: grey and maroon shale, brown dolostone and, in places, salt, anhydrite and gypsum; consists predominantly of evaporitic rich material with up to eight units identifiable. THICKNESS: 113 to 183 m. USES: gypsum mines at Hagersville, Caledonia and Drumbo; salt is mined at Goderich and Windsor and is produced from brine wells at Amherstburg, Windsor and Sarnia.

Bertie and Bass Islands Formations (Upper Silurian)

STRATIGRAPHY: Bertie Formation found in southern Niagara Peninsula; Bass Islands Formation, the Michigan Basin equivalent of the Bertie Formation, does not significantly outcrop in Ontario but is present in the subsurface in southwestern Ontario; Bertie Formation represented by Oatka, Falkirk, Scajaquanda, Williamsville and Akron members. COMPOSITION: medium- to massive-bedded, micro-crystalline, brown dolostone with shaly partings. THICKNESS: 14 to 49 m. USES: quarried for crushed stone on the Niagara Peninsula at Fort Erie, Cayuga, Hagersville and Dunnville; shaly intervals are unsuitable for use as high specification aggregate because of low freeze-thaw durability; has also been extracted for lime. AGGREGATE SUITABILITY TESTING: PSV = 46-49, AAV = 8-11, $MgSO_4$ = 4-19, LA = 14-23, Absn = 0.8-2.8, BRD = 2.61-2.78, PN (Asphalt & Concrete) = 102-120.

Oriskany Formation (Lower Devonian)

STRATIGRAPHY: basal Devonian clastic unit, found in Niagara Peninsula. COMPOSITION: thick- to massive-bedded, coarse-grained, grey-yellow sandstone. THICKNESS: 0 to 5 m. USES: has been quarried for silica sand, building stone and armour stone; may be acceptable for use as rip rap and well cemented varieties may be acceptable for some asphaltic products. AGGREGATE SUITABILITY TESTING: (of a well cemented variety of the formation) PSV = 64, AAV = 6, $MgSO_4$ = 2, LA = 29, Absn = 1.2-1.3, BRD = 2.55, PN (Asphalt & Concrete) = 107.

Bois Blanc Formation (Lower Devonian)

STRATIGRAPHY: Springvale Sandstone Member forms the lower portion of formation. COMPOSITION: a cherty limestone with shale partings and minor interbedded dolostones; Springvale Sandstone Member is a medium- to coarse-grained, green glauconitic sandstone with interbeds of limestone, dolostone and brown chert. THICKNESS: 3 to 40 m. USES: quarried at Hagersville, Cayuga and Port Colborne for crushed stone; material generally unsuitable for concrete aggregate because of high chert content. AGGREGATE SUITABILITY TESTING: PSV = 48-53, AAV = 3-7, $MgSO_4$ = 3-18, LA = 15-22, Absn = 1.3-2.8, BRD = 2.50-2.70, PN (Asphalt & Concrete) = 102-290.

Onondaga Formation (Middle Devonian)

STRATIGRAPHY: correlated to part of the Detroit River Group; occurs on the Niagara Peninsula from Simcoe to Niagara Falls; contains the Edgecliff, Clarence and Moorehouse members. COMPOSITION: medium-bedded, fine- to coarse-grained, dark grey-brown or purplish brown, variably cherty limestone. THICKNESS: 18 to 25 m USES: quarried for crushed stone on the Niagara Peninsula at Welland and Port Colborne; high chert content makes much of the material unsuitable for use as concrete aggregate and asphaltic concrete; has been used as a raw material in cement manufacture. AGGREGATE SUITABILITY TESTING: (Clarence and Edgecliff members) $MgSO_4$ = 1-6, LA = 16.8-22.4, Absn = 0.5-1.1, PN (Asphalt & Concrete) = 190-276.

Amherstburg Formation (Middle Devonian)

STRATIGRAPHY: part of Detroit River Group; correlated to Onondaga Formation in Niagara Peninsula; contains Sylvania Sandstone Member and Formosa Reef Limestone. COMPOSITION: bituminous, bioclastic, stromatoporoid-rich limestone and dolostone with grey chert nodules; Formosa Reef Limestone is high purity (calcium rich) limestone; Sylvania Sandstone Member is quartz sandstone. THICKNESS: 0 to 50 m; Formosa Reef Limestone up to 26 m. USES: cement manufacture, agricultural lime, aggregate. AGGREGATE SUITABILITY TESTING: PSV = 57, AAV = 19, $MgSO_4$ = 9-35, LA = 26-52, Absn = 1.1-6.4, BRD = 2.35-2.62, PN (Asphalt & Concrete) = 105-300.

Lucas Formation (Middle Devonian)

STRATIGRAPHY: part of the Detroit River Group in southwestern Ontario; includes the Anderdon Member which, in the Woodstock Beachville area, may constitute the bulk of the formation. COMPOSITION: light brown or grey-brown dolostone with bituminous laminations and minor chert; Anderdon Member consists of very high purity (calcium-rich) limestone. THICKNESS: 40 to 75 m. USES: most important source of high-purity limestone in Ontario; used as calcium lime for metallurgical flux and for the manufacture of chemicals; rock of lower purity is used for cement manufacture, agricultural lime and aggregate; Anderdon Member is quarried at Amherstburg for crushed stone. AGGREGATE SUITABILITY TESTING: PSV = 46-47, AAV = 15-16, $MgSO_4$ = 2-60, LA = 22-47, Absn = 1.1-6.5, BRD = 2.35-2.40, PN (Asphalt & Concrete) = 110-160.

Dundee Formation (Middle Devonian)

STRATIGRAPHY: few natural outcrops, largely in the subsurface of southwestern Ontario. COMPOSITION: fine- to medium-crystalline, brownish grey, medium- to thick-bedded, dolomitic limestone with shaly partings, sandy layers and chert in some areas. THICKNESS: 15 to 30 m. USES: quarried near Port Dover and on Pelee Island for crushed stone; used at St. Marys as a raw material for Portland cement. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-28, LA = 22-46, Absn = 0.6-6.8, PN (Asphalt & Concrete) = 125-320.

Marcellus Formation (Middle Devonian)

STRATIGRAPHY: subsurface unit, mostly found below Lake Erie and extending into the eastern U.S.A., pinches out in the Port Stanley area. COMPOSITION: black, bituminous shales. THICKNESS: 0 to 5 m. USES: no present uses.

Bell Formation (Middle Devonian)

STRATIGRAPHY: lowest formation of the Hamilton Group, no outcrop in Ontario. COMPOSITION: soft blue and grey calcareous shale. THICKNESS: 0 to 9 m. USES: no present uses.

Rockport Quarry Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group; no outcrop in Ontario. COMPOSITION: grey-brown, very fine-grained limestone with occasional shale layers. THICKNESS: 0 to 6 m. USES: no present uses.

Arkona Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: blue-grey, plastic, clay shale with occasional thin and laterally discontinuous limestone lenses. THICKNESS: 5 to 37 m. USES: has been extracted at Thedford and near Arkona for the production of drainage tile.

Hungry Hollow Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: grey crinoidal limestone and soft, fossiliferous calcareous shale. THICKNESS: 0 to 2 m. USES: suitable for some crushed stone and fill with selective quarrying. AGGREGATE SUITABILITY TESTING: No data.

Widder Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: mainly soft, grey, fossiliferous calcareous shale interbedded with blue-grey, fine-grained fossiliferous limestone. THICKNESS: 0 to 14 m. USES: no present uses.

Ipperwash Formation (Middle Devonian)

STRATIGRAPHY: upper formation of the Hamilton Group; very limited distribution. COMPOSITION: medium- to coarse-grained, grey-brown, bioclastic

limestone. THICKNESS: 2 to 14 m. USES: no present uses.

Kettle Point Formation (Upper Devonian)

STRATIGRAPHY: occurs in a band between Sarnia and Erieau; small part overlain by Port Lambton Group rocks in extreme northwest. COMPOSITION: black, highly fissile, organic-rich shale with minor interbeds of grey-green silty shale. THICKNESS: 0 to 61 m. USES: possible source of fill; possible source of material for use as sintered lightweight aggregate.

Bedford Formation (Upper Devonian)

STRATIGRAPHY: lower formation of the Port Lambton Group. COMPOSITION: soft, grey shale. THICKNESS: 0 to 33 m. USES: no present uses.

Berea Formation (Upper Devonian)

STRATIGRAPHY: middle formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: grey, fine- to medium-grained sandstone, often dolomitic and interbedded with grey shale and siltstone. THICKNESS: 0 to 60 m. USES: no present uses.

Sunbury Formation (Upper Devonian)

STRATIGRAPHY: upper formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: black shale. THICKNESS: 0 to 20 m. USES: no present uses.

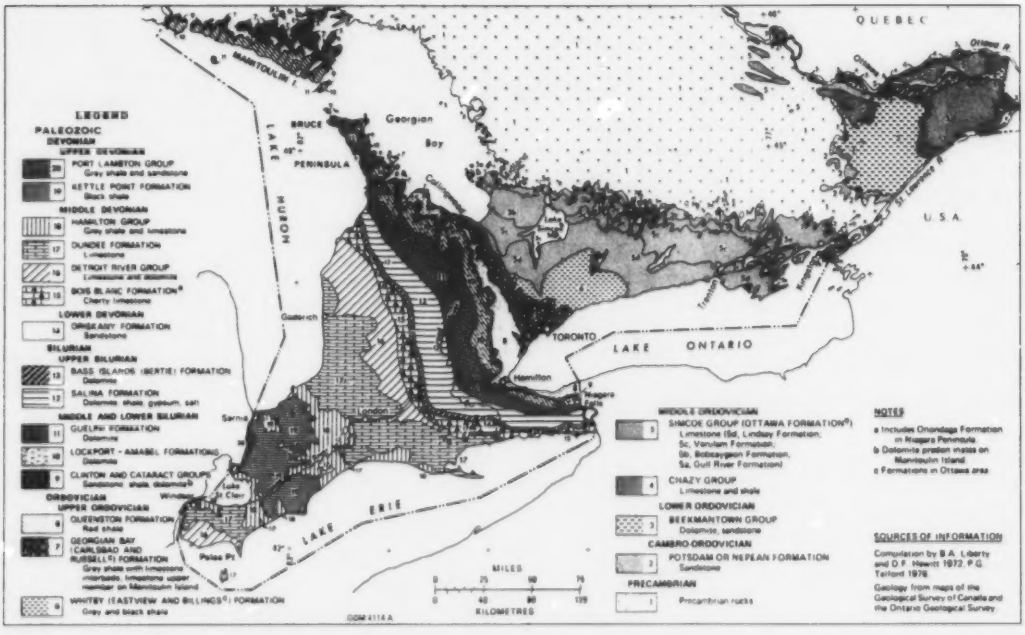

Figure D1. Bedrock geology of southern Ontario.

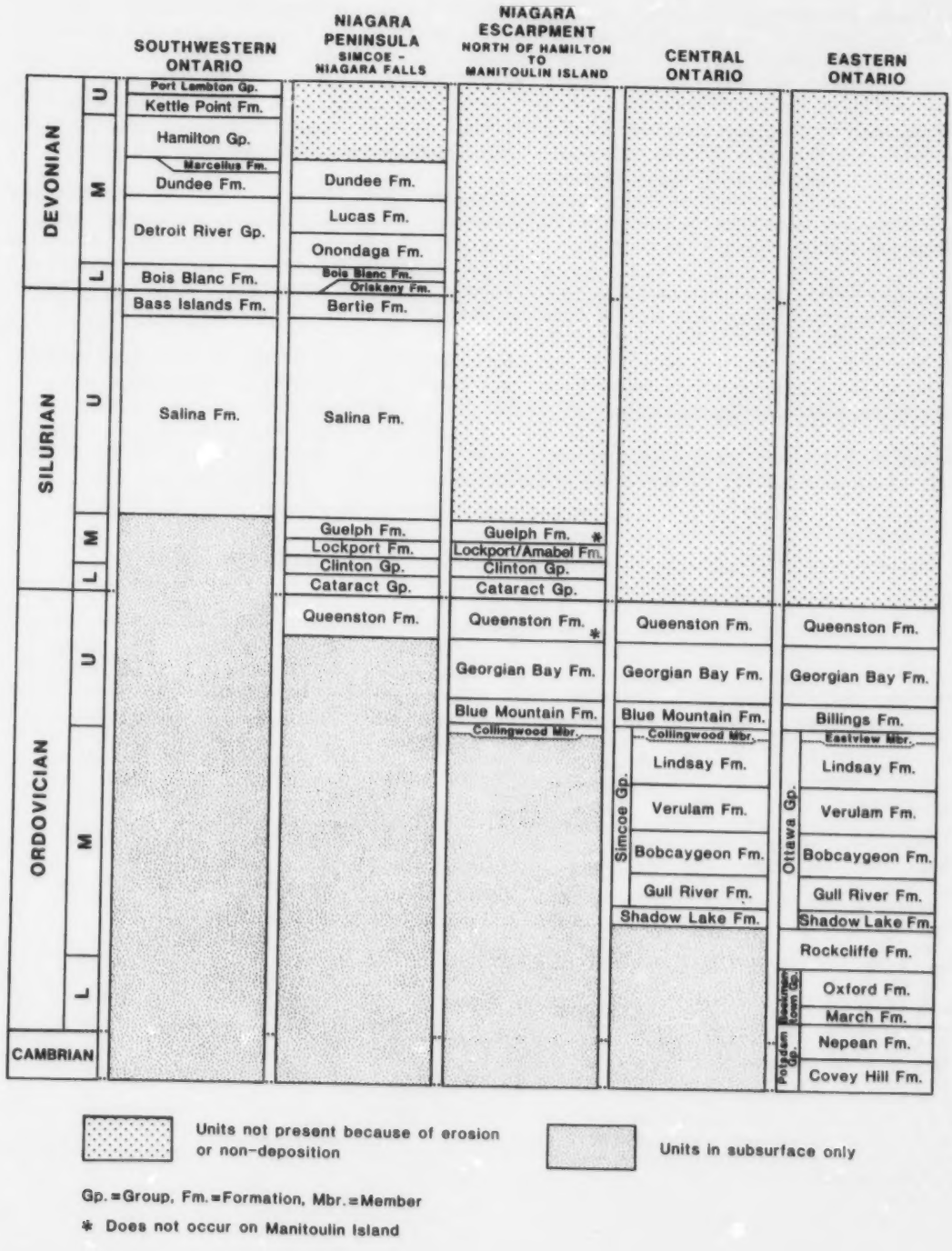

Figure D2. Exposed Paleozoic stratigraphic sequences in southern Ontario (adapted from: Bezys, R. K. and Johnson, M.D. 1988. The geology of the Paleozoic formations utilized by the limestone industry of Ontario; The Canadian Mining and Metallurgical Bulletin, v.81, no.912, p.49–58).

Appendix E — Aggregate Quality Testing

Four types of aggregate quality tests have been performed on selected samples from the project area. A description and the specification limits for each test are included in this appendix. Although a specific sample meets or does not meet the specification limits for a certain product, it may or may not be acceptable for that use based on field performance. Additional quality tests other than the four major tests listed in this appendix can be used to determine the suitability of an aggregate. The above four types of tests were performed by the Ontario Ministry of Transportation.

Absorption Capacity Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate. This test is conducted in conjunction with the determination of the sample's relative density.

Los Angeles Abrasion and Impact Test This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium Sulphate Soundness Test This test is designed to simulate the action of freezing and thawing on aggregate. Those aggregates which are susceptible will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Petrographic Examination Individual aggregate particles in a sample are divided into categories good, fair, poor and deleterious, based on their rock type (petrography) and knowledge of past field performance. A petrographic number (PN) is calculated. The higher the PN, the lower the quality of the aggregate.

TABLE E1. SELECTED QUALITY REQUIREMENTS FOR MAJOR AGGREGATE PRODUCTS.

	TYPE OF TEST				
	COARSE AGGREGATE				FINE AGGREGATE
TYPE OF MATERIAL	Petrographic Number Maximum	Magnesium Sulphate Soundness Maximum % Loss	Absorption Maximum %	Los Angeles Abrasion Maximum % Loss	Magnesium Sulphate Soundness Maximum % Loss
Granular A	200	-	-	60	-
Granular B Type I	250*	-	-	-	-
Granular M	200	-	-	60	-
Select Subgrade Material	250	-	-	-	-
Surface Treatment Class 1	135	12	1.75	35	-
Surface Treatment Class 2	160	15	-	35	-
Surface Treatment Class 3	160	12	2.0	35	-
Surface Treatment Class 4	-	-	-	-	20
Surface Treatment Class 5	135	12	1.75	35	-
Hot Mix - HL 1	100	5	1.0	15	16
Hot Mix - HL 2	-	-	-	-	20
Hot Mix - HL 3	135	12	1.75	35	16
Hot Mix - HL 4	160	12	2.0	35	20
Hot Mix - HL 8	160	15	2.0	35	20
Structural Concrete, Sidewalk, Curb, Gutter and Base	140	12	2.0	50	16
Pavement Concrete	125	12	2.0	35	16

* requirement waived if the material has more than 80% passing the 4.75 mm sieve.

(Ontario Provincial Standard Specifications OPSS 304, OPSS 1002, OPSS 1003 and OPSS 1010)

CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

MAPS
NOT
FILMED

CARTES
OMISES